LEVEL II

IDENTIFICATION AND SCREENING OF REMOTE MINE DETECTION TECHNIQUES

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report documents the technical effort and results achieved for the task of identification and screening of promising remote sensing systems and other methods of detecting and identifying mines, minefields, minelaying equipment or minelaying operations and recommends continuing effort on the most promising methods. Systems considered under this task include systems presently in use, systems on which research and development is currently being

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20.   ABSTRACT (CONTINUED)

conducted, and systems with potential for future development. Emphasis in
the study was placed on detecting surface-laid minefields in the European
theater with short detection reaction times.

    Continued effort is recommended on aerial photography, with particular
attention paid to rapid processing and delivery of imagery to the local
commander. Field tests of the Spotlight radar, being conducted under another
task of this project, may give quantitative information of its mine detection
capability, on the basis of which further effort on this type of radar can
be planned. Of the electro-optical scanners, the active scanner most nearly
approaches a 24-hour data collection capability, with multispectral scanners
and passive infrared scanners having more restricted capability. Further
effort should be devoted to the investigation of all three types with highest
priority given to continuing the investigation of the 10.6 micrometer active
scanner currently being conducted under this project.

    Image intensifiers and television devices have only limited potential
for detecting mines and minefields. SIGINT systems are believed to have
little or no potential for minefield location. Explosive detection techniques
do not lend themselves readily to remote minefield detection because the
detectors' use involves bringing them in proximity to a mine. Some of the
techniques involve the use of taggants in the explosives, a cooperative ven-
ture which cannot be expected of an enemy in wartime.

    MTI and pulse Doppler radars and acoustic and seismic sensors have capa-
bilities primarily useful for providing inferential information which could
be used for cueing purposes. These sensors are discussed, but recommendations
on the further investigation of such sensors are not covered in this report.

    No one sensor stands out as the best mine detector from the technical
standpoint. From the system viewpoint, coupling more than one sensor
technique together appears to offer the greatest likelihood for surface mine-
field detection.

ΣERIM

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FIGURES

TABLES

TABLE (Continued)

IDENTIFICATION AND SCREENING OF
MINEFIELD DETECTION SYSTEMS

1
INTRODUCTION

The objective of the minefield detection project is to determine
the effectiveness of remote sensing systems and other methods of de-
tecting and identifying mines, minefields, minelaying equipment, or
minelaying operations, and to recommend continuing effort on the most
promising methods.

Work under the project concerned with each of the concepts to be
investigated is being performed in a sequence of four major tasks:
(1) identification and screening of promising techniques; (2) prelim-
inary systems analysis and definition of experimental or other data
acquisition systems; (3) acquisition of critical data through experi-
ment, literature survey, or access to SCI; and (4) evaluation of con-
ceptual systems for technical performance and military usefulness.

This report documents the technical effort and results achieved
for the task of identification and screening of promising techniques
through June 1978. The task is a continuing one, and further task
activity will be covered in subsequent reports.

The objectives of Task I are to identify and screen those U.S.
surveillance assets that may have applicability in detecting mines
and/or minefields either directly or by inference. The identifica-
tion and screening is to be based on the technical characteristics
and performance of these surveillance assets (both ground and air-
borne) that may be available to support countermine operations in
the combat theater. Individual types of techniques and equipment
are to be identified as to their operational status, specifically
(1) currently operational sensor systems, (2) planned sensor systems,
and (3) new systems.

This task results in the selection of those techniques and system concepts which have the best potential for meeting the technical constraints and requirements for the mine detection mission. The selected techniques can be subjected to further analysis, data acquisition, and evaluation during Tasks II, III, and IV.

1.1 APPROACH TO IDENTIFICATION AND SCREENING

The ERIM approach to the identification and screening process is illustrated in Figure 1-1. Considering a set of minefield characteristics, a set of sensor characteristics and a set of sensor carrier vehicle characteristics, the region of commonality, if it exists, may be considered to represent a region of mutual compatibility where the constraints of all three are satisfied in terms of technical feasibility for minefield detection.

1.1.1 MINEFIELD CHARACTERISTICS

Minefield characteristics include a description of the individual mine and its distinguishing features, the use of the mine in a minefield, the doctrine, tactics and methods of minefield employment, the scenario for its use, the characteristics of the region where it is employed and the various inferential uses associated with it.

This program is concerned chiefly with the anti-tank (AT) and anti-vehicular (AV) mines used by the Soviet Bloc. Several mine types are of specific interest, including the PM-60 and the TM-46.

1.1.1.1 Scenarios

The identification and screening task is being conducted with reference to four scenarios which have been defined by BDM Corp. These scenarios are typical examples of doctrine, tactics, and methods of Soviet use, together with typical equipments, time frames and areas involved. The terrain of interest is the West German border
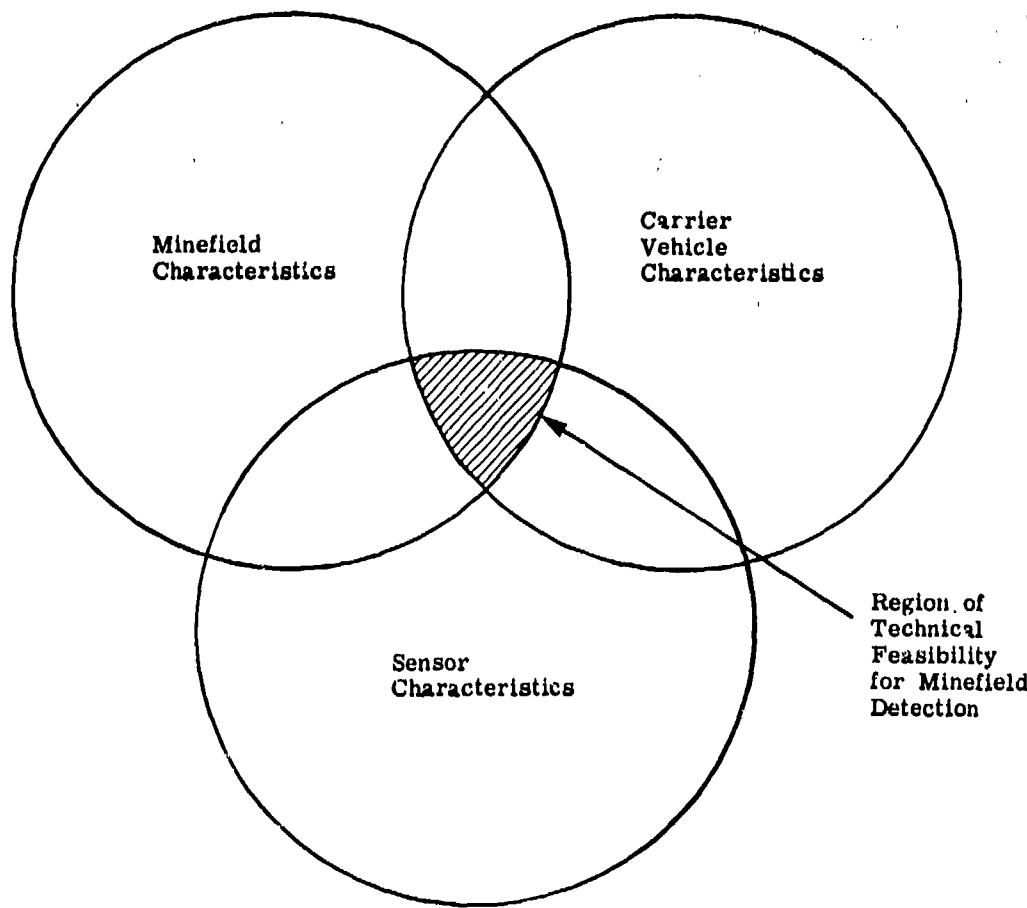
FIGURE 1-1. CANDIDATE SCREENING PROCESS

The circles in the diagram are labeled: Minefield Characteristics, Carrier Vehicle Characteristics, Sensor Characteristics, and Region of Technical Feasibility for Minefield Detection.

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areas which are generally exemplified by flat plains to the north and rolling terrain to the south. Some of the basic characteristics of the four scenarios are given in Figure 1-2.

The general characteristics of these scenarios are summarized as follows:

1. Scenarios A, B, and C are for offensive operations and are characterized as hasty operations with mines being in place a relatively short time. Emplacement and recovery times are significant with respect to in-place times. Scenarios A and B have all their mines surface laid. Scenario C has a great majority of its mines surface laid.

2. Scenario D is for defensive operations and is characterized as a deliberate operation with mines expected to be in place a relatively long time. All mines are buried.

1.1.1.2 Scenario Imposed Constraints Affecting Technical Characteristics

The technical implications of these scenarios have been developed for use in our initial screening and may be summarized as follows:

1. There is a predominance of surface mines and minefields in the scenarios, but buried mines and minefields must also be considered.

2. Since the Soviet forces have a 24-hour fighting capability and the in-place times for the offensive minefields is relatively short, the sensors should ideally have a capability to operate both day and night.

3. An all-weather sensor capability is highly desirable in view of the short in-place times of the offensive minefields. Weather and terrain to be considered in technical screening are those typical of the North German Plain, the Fulda Gap and Hof Corridor.

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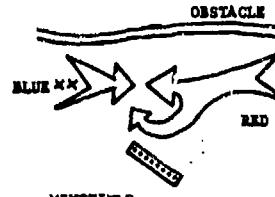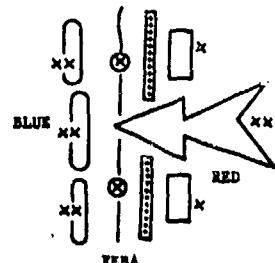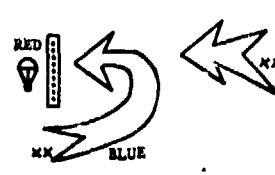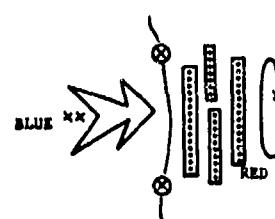
MINE WARFARE MISSION	DOCTRINE AND TACTICS	TYPE OF OPERATION	LENGTH OF TIME MINE FIELD IN PLACE	TYPE OF MINES	NUMBER OF MINES
A. PROTECT MOST EXPOSED FLANK DURING MEETING ENGAGEMENT	OBSTACLE / BLUE XX / RED / MINEFIELD	OFFENSIVE	1 HOUR	PM 60 SURFACE (Plastic)	545 (50 x 1000 meters area)
B. PROTECT SHOULDERS DURING BREAKTHROUGH (ECONOMY OF FORCE)	BLUE XX / XX / RED / FEBA	OFFENSIVE	20 HOURS	TM 46 SURFACE (Metal)	750 (150 x 1000 meters area)
C. BLOCK ENEMY WITHDRAWAL	RED / RED / XX / XX BLUE	OFFENSIVE	8 HOURS	TM 46 SURFACE (Metal)	60 (50 x 100 meters area)
				PM-60 BURIED (Plastic)	7 within 50 meter radius
D. SUPPORT PREPARED DEFENSE	BLUE XX / XX / RED	DEFENSIVE	INDEFINITE	TM 46 (Metal) or MV 5 (Metal)	545 (150 x 100 meters)

FIGURE 1-2. FOUR MAJOR SCENARIOS FOR SOVIET MINE WARFARE OPERATIONS

4. To be effective against scenarios A, B, and C, the sensor/
carrier vehicle combination must have a quick reaction time.
Sensor/carrier vehicle combinations must be capable of quick-
ly covering areas containing minefields of interest, together
with their ancillary operations and installations and trans-
ferring information of interest to the local unit commander
in a timely fashion so that he may have time to react to the
enemy offensive operation. Time factors to be considered
include the time required for minefield emplacement, elapsed
time to encounter, and total time in place.

5. The sensor/carrier vehicle combination must not be unduly
vulnerable to enemy actions designed to defeat the successful
performance of their minefield detection mission. The pres-
ence of formidable enemy ground and air defenses associated
with these scenarios can be expected. Further, there are
significant technical performance restraints imposed on the
space/time regime allowed to the sensor/carrier vehicle which
can significantly affect its vulnerability.

1.1.2 PLATFORM-IMPOSED CONSTRAINTS

In addition to the minefield and sensor characteristics, the
sensor/carrier-vehicle characteristics must be examined for compati-
bility and availability. The carrier vehicle must be capable of
operating with acceptable survivability in the space/time regime re-
quired in order for the sensor to detect minefields and for the sys-
tem to perform the mine detection mission for the Army. Further, it
must be able to accommodate the physical installation of the sensor
and provide the necessary power and other ancillary items to support
the operation of the sensor (see Table 1-1).

A variety of platforms are potentially capable of operating with-
in these constraints depending on specific circumstances. These
platforms fall within the categories listed in Table 1-2.

TABLE 1-1
PLATFORM IMPOSED CONSTRAINTS AFFECTING
TECHNICAL CHARACTERISTICS

1. Mission Profile Capability

2. Mission Duration

3. Vulnerability and Survivability Envelope of the Platform
   and Associated Equipment

4. Payload Capability

5. Data Link Requirements

6. Command and Control Requirements

7. Power Limitations

TABLE 1-2
GENERIC PLATFORM TYPES

Aircraft

Helicopters

Remotely Piloted Vehicles (RPV's)

Ground Vehicles

Satellites

Others

1.1.3 SENSOR TECHNICAL PERFORMANCE CHARACTERISTICS

A number of technical performance characteristics of the sensor system must be considered for compatibility with the minefield characteristics and platform characteristics discussed above. The most important of these characteristics are the following:

1. The probability that a sensor will detect an individual mine under specified constraints is expressed in terms of probability of detection of individual mines. It is also of importance to determine the incorrect performance of the system, expressed in terms of false alarms and missed identifications, since these failures can have significant consequences in accomplishing military objectives.

2. The detection of individual mines is only a step toward recognition of complete minefields. Consequently, a significant measure of system performance is the ability to infer the existence of a minefield, given certain probabilities of detection of the individual mine. This capability may be a performance characteristic associated with the data processing system, rather than the sensor itself.

3. The statistics of mine and minefield detection refer only to those areas actually observed by the sensor. It is necessary to account for areas not covered by the sensor because of obscuration by the terrain, vegetation, weather, etc. This characteristic is referred to here as target accessibility. A preliminary definition of target accessibility will be used for purposes of generic screening. Later in the program, when specific sensors have been selected for analysis, target accessibility will be defined separately for each candidate.

4. Another measure of sensor/vehicle performance is its rate of area coverage. This rate affects the cost and timeliness of the operation.

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5. As indicated earlier, the ability to provide timely data is of great importance for several of the scenarios. Consequently, elapsed time between ordering a mission and receiving the technical outputs of the sensor for decision making will determine usefulness of the resulting information.

6. The susceptibility of the sensor and associated equipment to countermeasures is of great importance. This includes both electronic and other countermeasures which can significantly degrade or nullify sensor performance to the point where mission performance is jeopardized.

7. The development status of a sensor determines its availability for use in various time frames.

The technical performance characteristics discussed above are summarized in Table 1-3.

1.2 SCOPE OF THE REPORT

The screening process covered by this report is intended to highlight those generic sensor types which have potential for detecting mines or minefields and to eliminate those which have little or no potential. The scope of this screening process is restricted to consideration of technical characteristics of the sensor and/or vehicle, that is, to the technical ability of the sensor to detect, identify, and locate mines or minefields with adequate reliability. For that reason, a generic type of sensor will be eliminated from further consideration only on the basis of technical capability. Operational considerations for screening out a sensor will be considered separately. For that purpose, this report contains information on sensor characteristics which will influence the subsequent operational screening process.

A distinction is also made between sensors which directly detect mines and those which provide only inferential information. Those

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TABLE 1-3
TECHNICAL PERFORMANCE CHARACTERISTICS

Probability of Detection of Individual Mines

Probability of False Alarm

Probability of Detection of Minefields

Probability of Target Accessibility

Rate of Area Coverage

Elapsed Time for Technical Outputs

Susceptibility to Countermeasures

Development Status

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sensor types which provide inferential information only, for example,
indications of the presence of minelaying vehicles and personnel,
have been separately designated. Such inferential information serves
only to provide cues to operators using sensors capable of detecting
mines. Consideration of sensors providing infere_ial or cueing in-
formation should be screened as an aspect of the study of operational
methods of directing or controlling mine detection sensors.

1.3 SUMMARY

For purposes of identification and screening of minefield detec-
tion sensors, a listing of sensors was prepared with assistance from
BDM Corp. (Section 2). The complete list includes sensors presently
in use by the armed services, as well as sensors based on techniques
currently in various stages of conceptualization or research and
development. In the identification and screening process, attention
is first directed to the characteristics of generic types of sensors
to determine which of these types offers the greatest potential for
use in minefield detection.

The ultimate purpose of mine detection systems is to detect in-
dividual mines and to identify the locations and extent of complete
minefields. Since mines are usually laid in regular patterns, it is
possible to identify the location and extent of the complete mine-
field by pattern recognition methods. Section 3 discusses two gen-
eral approaches to pattern recognition, the use of human photointer-
pretation and computer-based pattern recognition. A specific pattern
recognition technique, the "antenna farm" algorithm, described in
Section 3.3, allows the recognition of linear configurations of
rather regularly spaced mines in an image which also contains
clutter.

Further study should be devoted to methods of detecting and
recognizing ordered and randomized minefields. This examination

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should also consider the problem of recognizing minefields by the
use of sensors able to to see only a portion of the minefield on a
single pass. Methods of recognizing minefields from only a small
number of mines or of using efficient flight paths or scanning pat-
terns should be studied. In addition, the criteria governing the
definition of a minefield (its location, orientation, length, gaps,
etc.) needs to be further explored.

Section 4 discusses the applicability of various generic type of
sensors to the minefield detection problem.

Several generic types of sensors considered during the screening
process have capabilities primarily useful for providing inferential
information which could be used for cueing purposes. Those sensors,
namely MTI and pulse Doppler radars (Section 4.2.2) and acoustic and
seismic sensors (Section 4.5) are discussed, but recommendations on
the further investigation of such sensors are not covered in this
report.

Aerial photography is fully developed and in widespread use by
the Armed Forces (Section 4.1). Aerial photography has the major
advantage of providing high resolution imagery, which is an advantage
of providing high resolution imagery, which is an important consider-
ation for the mine detection application, where objects of relatively
small dimensions must be detected and identified. The vulnerability,
target accessibility, and response time of the method requires care-
ful consideration. To meet the need for fast reaction times, methods
of rapidly delivering imagery to the local commander through air
drops or data links should be considered. Because of the advantages
of aerial photography and its widespread availability, continued
effort on its application to minefield detection is recommended. A
technical example of the characteristics of aerial cameras carried
on an RF4C aircraft is given in Section 4.1.3 for use in operational
studies.

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Synthetic aperture radar is the only all-weather sensor with the potential for long range detection of surface minefields. The Spotlight radar is a form of synthetic aperture radar which can produce very fine resolution imagery. In addition to being the finest resolution airborne radar available, the Spotlight radar has high angular diversity (up to 90 degrees of azimuth angle swept on a single pass by a target scene), which increases the probability of detection. Field tests of the Spotlight radar being conducted under another task of this program will give quantitative information of its mine detection capability, on the basis of which further effort on the investigation of this type of radar can be planned.

The synthetic aperture radar has substantial advantages over real aperture radars with respect to resolution. Consequently, continued investigation of synthetic aperture radar has higher priority than investigation of real aperture radar.

No further investigation of non-linear radar is recommended at this time.

The electro-optical scanners can all detect surface mines, with active 10.6 micrometer scanners potentially having the greatest capability, followed by multispectral scanners, and passive infrared scanners. Consequently, highest priority should be given to further investigation of the active scanner.

The active scanner has the advantage of being able to operate both day and night. Tests conducted under another task of this program indicate that an active scanner is able to detect mines and that a strong return within a narrow angle is received from the flat surfaces of the mines.

Multispectral sensors may have better ability to detect mines and to differentiate between mines and false targets than do single spectrum infrared scanners. However, more experimental data are needed to validate the capabilities of these sensors.

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Passive infrared sensors can detect mines under some circumstances, but are restricted by cloud cover, fog, and rain, and are ineffective when appreciable temperature differences between the mine and its background do not exist. Limitations on sensor resolution also restrict the detection range for individual mines. Those sensors which offer a higher potential for working under a wide variety of conditions should receive higher priority in investigation over passive infrared sensors.

The use of image intensifiers by ground-based personnel or vehicles is limited because of the low depression angle with which they must be observed in the presence of vegetation or terrain roughness. The use of image intensifiers from an aircraft is not a simple task, since the restricted field of view complicates the problem of determining the location of the mines.

Television is a potential candidate for detecting mines and minefields during daytime. However, the range at which mines could be detected by a television carried on an RPV would be limited.

SIGINT systems are believed to have little or no potential for minefield location, and no further consideration of their use is recommended at this time.

No one sensor stands out as the best mine detector from the technical standpoint. From the system viewpoint, coupling more than one sensor technique together appears to afford the greatest likelihood for surface minefield detection. For example, an MTI radar for cueing might be coupled with a synthetic aperture radar for mine and minefield detection.

A summary matrix covering the generic types of sensors and the governing characteristics for their potential as minefield detectors is presented in Section 5. Conclusions and recommendations for further effort are also detailed in this section.

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2
IDENTIFICATION AND CATEGORIZATION OF SENSORS

The process of screening sensor candidates involves consideration of not only the technical performance of the sensors, but also the suitability of these techniques or systems when considered in the light of operational requirements. In this report, emphasis is placed on the work done in identifying and selecting the sensor types and characteristics and defining them to the point where they can be further assessed by the application of operational models. The generalized procedure for doing this technical screening is shown in Figures 2-1 and 2-2.

Figure 2-1 shows the steps involved in the selection of sensor types for operational evaluation. The objective of the work covered by Figure 2-1 is to prepare technical characterizations of representatives of promising generic sensors which can be used as inputs to operational models for evaluation of the selected sensors. Effort on this first part of the technical screening process is the particular subject matter of this report.

As shown in Figure 2-1, the process of surveying and cataloging opportunities for mine and/or minefield detection was based on a listing of sensors derived from two sources. BDM Corp. supplied ERIM with a list of current sensor programs of the armed services which have potential applicability to the minefield detection study. A supplemental list was prepared by ERIM for additional sensor types included in current or planned sensor programs of the armed services which have potential applicability to the study. This list includes sensors based on techniques currently in various stages of conceptualization or research and development.

In order to simplify and expedite analysis of this large number of individual sensors, they were organized into a relatively limited number of generic sensor types (see Table 2-1). A listing of the

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┌─────────────────────────────────────────────────┐
│         SURVEY AND CATALOG OPPORTUNITIES          │
│      FOR MINE AND/OR MINEFIELD DETECTION.         │
│      A.  BDM LIST (CURRENT SENSOR PROGRAMS)       │
│      B.  ERIM LIST (ADDITIONAL SENSORS)           │
└─────────────────────────────────────────────────┘
                         │
          ┌──────────────────────────────────┐
          │ CATEGORIZE BY GENERIC SENSOR TYPES │
          └──────────────────────────────────┘
                         │
┌──────────────────────────────────────────────────────┐
│      EXAMINE GENERIC SENSOR TYPES FOR GENERALIZED      │
│          CAPABILITIES IN LIGHT OF GIVEN SCENARIOS      │
│                                                        │
│  TARGET SIGNATURES, BACKGROUND MOTIONS, EMISSIONS, PLATFORM, RE- │
│  QUIREMENTS, IOC, EXISTENCE OF MINE AND/OR MINEFIELD DE- │
│  TECTION TEST RESULTS, ETC.                            │
└──────────────────────────────────────────────────────┘
                         │
┌──────────────────────────────────────────────────────┐
│  SELECT MOST PROMISING GENERIC SENSOR TYPES FOR DETAILED │
│  TECHNICAL CHARACTERIZATION AND STATE RATIONALE FOR CHOICES │
└──────────────────────────────────────────────────────┘
                         │
FROM "EXPLORE OTHERS OF
SAME GENERIC CLASS"
                         │
┌──────────────────────────────────────────────────────┐
│  SELECT A REPRESENTATIVE SENSOR FOR EACH APPLICABLE GENERIC │
│  SENSOR TYPE AND CHARACTERIZE TECHNICALLY IN DETAIL.   │
└──────────────────────────────────────────────────────┘
                         │
      ┌───────────────────────────────────────┐
      │   DEVELOP INPUTS FOR OPERATIONAL MODEL  │
      └───────────────────────────────────────┘
                         │
          ┌──────────────────────────┐
          │   TO OPERATIONAL MODEL    │
          └──────────────────────────┘
```

FIGURE 2-1. APPROACH TO TECHNICAL SCREENING
A. Selection of Sensor Types for Application to Operational Model

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OUTPUTS FROM OPERATIONAL MODEL

SENSOR TYPE REJECTED

SENSOR TYPE SUITABLE IF MODIFIED

SENSOR TYPE SUITABLE

INVESTIGATE TECHNICAL FEASIBILITY OF MODIFICATION

MODIFICATION NOT TECHNICALLY FEASIBLE

MODIFICATION TECHNICALLY FEASIBLE

DEFINE SUFFICIENTLY FOR USE IN CONCEP- TUAL DEFINITION AND ANALYSIS, TASK 2

EXPLORE OTHERS OF SAME GENERIC CLASS

TO SELECTION OF MOST PROM- ISING SENSOR TYPES IN GENERIC CLASS

FIGURE 2-2. APPROACH TO TECHNICAL SCREENING

B. Operational Model Screening of Sensors

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TABLE 2-1
GENERIC SENSOR TYPES

Photographic Systems

Radars
    Imaging - SAR, Real Aperture, Hologram
    MTI
    Pulse Doppler
    Non-Linear

Electro-Optical Systems
    Passive
        - Downward Looking
        - FLIR
    Active
        - Illuminator
        - 3-D Scanner
    Image Intensifiers
    Television Systems

Acoustic

Seismic

SIGINT
    ELINT
    RINT
    COMINT

Explosive Detection
    Animals
    Chemical Vapor
    Nuclear Magnetic Resonance
    X-Rays
    Neutrons

Detection by Detonation
    Acmes - Sacrificial Vehicle
    Reconnaissance by Fire
    Roller
    Slufae
    Demolition Gun - CEV

individual sensors which were initially reviewed in the identification and screening process is given in Tables 2-2 and 2-3. The BDM list of sensors consists of those presently under development or in use by the Armed Forces. The ERIM list adds other sensor types and techniques which are at various stages of operational use or in research and development.

Based on this listing of sensors, each of the generic sensor types was then assessed with respect to its generalized capabilities in the light of the selected scenarios and its potential adaptability for use in conjunction with existing or planned platforms.

The most promising generic sensor types were selected for further investigation and a representative sensor for each type was then postulated. A technical characterization of this representative sensor was prepared and used to develop inputs to an operational model for further assessment. Conclusions reached concerning each of the generic types and technical characterization of a sensor system representative of each promising type will be discussed in following sections.

Based on these results, the screening of candidate sensor systems will be continued by the analysis of their performance in operational models. Figure 2-2 shows the manner in which the outputs from the operational model are used to decide on further effort on individual sensor systems. Depending on the results of the operational modeling, the decision may be made to (1) reject the sensor type, (2) modify the sensor features and performance characteristics, where feasible, or (3) continue with further consideration of the sensor. Since the first operational modeling will be confined to studies of representative examples of generic classes of sensors, a finding that the sensor type is suitable will also lead to the decision to explore other sensors of the same class.

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TABLE 2-2
OPPORTUNITIES FOR MINEFIELD DETECTION

BDM LIST OF SENSORS

Sensor	Expected IOC	Platform
Photographic Systems		
KS-87A	In Operation	RF-4C
KA-56	In Operation	RF-4C
KA-91A, B	In Operation	RF-4C
KS-120		
Radar		
APS-94, MTI Radar	In Operation	OV-1D
Firefinder, AN/TPS-36 Mortar Tracker	1980/1981	Gamma Goat
SOTAS (Standoff Target Acquisition System), AMTI Radar	1983	UH-60
UPD-4, SLAR	In Operation	RF-4C
Electro-Optical Systems		
AAD-5, Infrared Scanner	In Operation	
Pave Tack, FLIR	Funds Denied	RF-4C, F4-E, F111F
KA-98, Laser Line Scanner		
SIGINT		
Rivet Joint		
Compass Ears		
Senior Spear		
Guardrail, AN/ARW-83, COMINT		
Quick Look II, AN/ALQ-133, ELINT	Production	Modified OV-1
TEREC II, Tactical Electronic Reconnaissance System, NON-COMM	3 Prototypes In Inventory, 18 Requested	RF-4C
Trailblazer, AN/TSQ-114		

ΣERIM

TABLE 2-3
OPPORTUNITIES FOR MINEFIELD DETECTION
ERIM LIST OF SENSORS

Sensor	Expected IOC	Platform
Radar		
Spotlight, Experimental SAR Operational Version	In Operation 1980's	
Firefinder, AN/TPS-37 Counter Battery Radar	1980/1981	Vans, Trucks
AN/PPS-5, Pulse Doppler	In Operation	1/4 Ton Truck, Tripod
AN/PPS-15 Radar	1st Quarter, 1980	
AN/TPS-21, Pulse Doppler Battlefield Radar	In Operation	Ground-Based
AN/TPS-33, Pulse Doppler Battlefield Radar	In Operation	Ground-Based
An/TPS-58, Battlefield Radar		
METTRA Close In	Program Cancelled	
VRMDS, Microwave		
BSTAR, Surveillance Radar	In Development	Ground-Based
Forward Area Alerting Radar, TPQ-32/MPQ-49	In Operation	Ground-Based
Acoustic/Seismic		
REMBASS, Acoustic, Seismic	In Development	Sensors Emplaced by Artillery
GR-8, Sound Ranging	In Operation	Ground-Based Microphone Array
FAALS	Program Cancelled	Acoustic Array
Electro-Optical		
AN/PVS-4 2nd Gen. Image Intensifier	1978	
AN/PVS-5 2nd Gen. Image Intensifier	1978	

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TABLE 2-3
OPPORTUNITIES FOR MINEFIELD DETECTION
ERIM LIST OF SENSORS (Continued)

Sensor	Expected IOC	Platform
Electro-Optical		
AN/TV5-4, 2nd Gen. Image Intensifier	1978	
SIGINT		
AGTELIS, (Automatic Ground Tactical Emitter Location Intercept System, TDOA)		Ground-Based
PLSS, Non-Comm. Emitter Location and Strike System		3 Aircraft
ELS, Communication Emitter Location System		3 Aircraft

3
PATTERN RECOGNITION

3.1 NEED FOR MINEFIELD PATTERN RECOGNITION

Several of the generic types of sensors considered in this report have sufficient resolution to detect individual mines, but may be unable to identify them as mines, particularly in the presence of clutter. Since mines are usually laid in regular patterns, it is possible to recognize a minefield on the basis of characteristic methods of Soviet employment such as the regular spacing of individual mines and the linear configuration of the array of mines. The use of pattern recognition methods may therefore lead to the identification of minefield segments, even though the individual mine may not be readily identifiable as such. Information useful to the local commander would consist not only of knowing the location of individual mines, but the location, direction, and extent of the minefield. In addition, information on gaps in the minefield would be valuable, if known with sufficient confidence that vehicles can be moved through these gaps.

Mine pattern recognition techniques can be employed with various imaging types of sensors. However, the adaptation of the technique to an individual type of sensor must take into account the characteristics of that sensor and its use. In particular, the ability of the pattern recognition process to detect linear patterns will depend on the density of clutter. Also, a sensor with a narrow field of view may observe only a short length of an extended mine pattern, limiting the number of mines which can be observed in identifying a pattern.

Techniques for recognition of minefield patterns should be studied for two reasons. In designing minefield detection systems, the opportunity exists of recognizing the presence of minefields by detecting the regular spatial pattern of an array of mines in the

presence of clutter. Also for evaluation purposes, the relationship
between the probability of detecting individual mines and the proba-
bility with which a complete minefield can be identified nees to be
defined.

3.2 PATTERN RECOGNITION APPROACHES

Two gener. l approaches to pattern recognition should be investi-
gated and compared: (1) human photointerpretation and (2) computer-
based pattern recognition algorithms.

Studies of human photointerpretation would be conducted by using
a number of human subjects, preferably persons representative of pho-
tointerpreters likely to be available ior this task during waitime.
Each subject would look at and analyze a set of photographs or simu-
lated or real images, and make decisions as to the presence or ab-
sence of minefields. These decisions would be scored on the basis
of correct detections, missed detections, and false alarms. The ex-
periments would be conducted with varying instructions to the subject
on the costliness of each type of error, and the scoring would be
adjusted accordingly, so that the effect of these costs on the sub-
ject's response could be determined.

The use of computer-based pattern recognition algorithms would
be investigated to determine their reliability and speed as a substi-
tute for human photointerpretation. Reference 1 is an example of
algorithms which have been developed for the recognition of linear
or non-linear features in images. Other promising computer-based
approaches should also be investigated. For example, one such
approach presently being considered, which has been nicknamed the
"antenna farm" algorithm, would use a Fourier analysis technique to
indicate the presence of a linear array of detected points in the
presence of clutter. This approach is described next.

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3.3 ANTENNA FARM ALGORITHM

The detection of minefields by their pattern will allow one to locate minefields in the presence of clutter without the requirement that mines must be identified individually by their signal characteristics. The following text describes a spatial pattern recognition algorithm for the recognition of minefield patterns.

The data required by this algorithm is an image or image data in numerical form of a ground area where the image scale is known. A spot detection process is applied to the image or image data so that any spot that even remotely might be a mine is plotted as a detection. A large number of counterfeits can be expected. These spot detections with x, y coordinates mapped in the image frame constitute the "Antenna Farm."

From N detections, we are to determine if some of these N lie in a partial mine field array. If some of them do fit the array pattern approximately, then, we are to determine which ones these are and where are the probable locations of the undetected mines that fit the missing part of the pattern.

Although this material for detecting mine fields by pattern is based upon Fourier techniques, it is entirely equivalent to the physical analogue of measuring antenna patterns of antenna arrays. Consequently, the picturesque name, ANTENNA FARM, is given to the algorithm and the antenna farm analogy makes the procedure cogent.

The image frame, with the spot detections plotted on it, is considered to be a map of an antenna farm where each point is an identical isotropic antenna driven in phase with a common generator. The wavelength of radiation can be adjusted at will. Figure 3.3-1 is an illustration of such an image with the tabulated coordinates shown in Table 3.3-1.

The received power in the far field is taken to be one unit of power when only one antenna is activated. When all antennas are

TABLE 3.3-1
DETECTION COORDINATES
(*) indicates a mine

| Detection Number	x	y
1	5	3
2*	1	7
3	23	7
4*	3	8
5	16	8
6*	7	10
7	7	11
8*	9	11
9*	11	12
10*	17	15
11	23	15
12*	21	17
13	13	18
14*	23	18
15*	27	20
16*	29	21
17	6	23
18	17	26
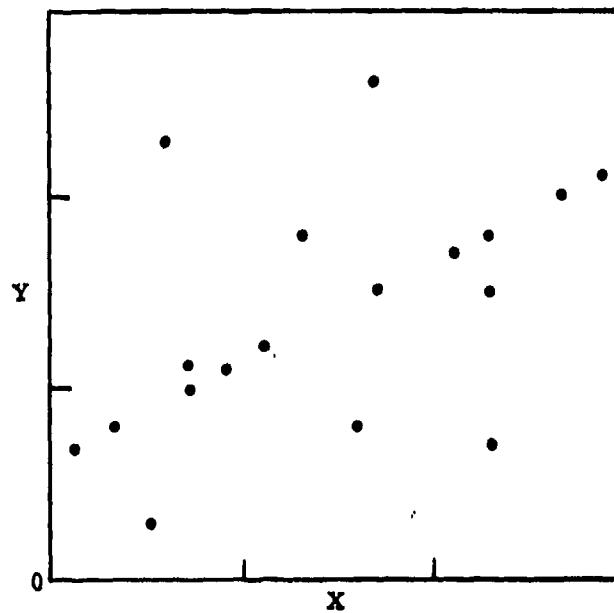
FIGURE 3.3-1. HYPOTHETICAL SPOT DETECTIONS

activated with high frequency power and, assuming that there are a
large number of antennas randomly distributed over the farm, we can
expect a very rapidly changing far field pattern in the horizontal
plane, changing pseudorandomly as the receiver changes azimuth. The
probability density of receiver power, ϕ, at a randomly chosen azi-
muth should be approximated by the Rayleigh distribution.

$$p(\phi) \cong \exp\ [-\phi/\phi(ave)]/\phi(ave) \tag{1}$$

The average value, $\phi(ave)$, over all azimuths must be exactly N, the
number of antennas.

However, if some n of these antennas are lined up in a linear
array, then when the azimuth of the receiver provides a broadside
view of this line, we can expect a received power of $(n \pm \epsilon)^2$ at some
angle, ψ, where ϵ represents the stochastic summation of amplitude
form from the other N - n randomly placed antennas.

The problem is first to adjust the wavelength so that the broad-
side pattern of an expected partial linear array representing the
spacing of a mine field will form a main lobe and to search in azi-
muth angle, ψ, for a received power which is improbable in a Rayleigh
distribution. Any main lobe which is found specifies the approximate
broadside direction, ψ, of an array. The next step is to test the
metric spacing of the suspected linear array. By viewing at 90° from
broadside, i.e., along the array, choose a wavelength which should
produce a main lobe in the direction of the array if the array had
the spacing of a mine field and test for the presence of improbably
high received power again. If both tests are passed, one can infer
that a non-random spacing of points occurs in the image and that the
spacing is commensurate with mine field spacing in the direction,
$\psi - 90^{\circ}$.

The final test is to determine if the points are colinear and,
if so, to locate that line. From the previous tests, we know the
approximate slope of the suspected array. The line,

$$y = \tan (\psi - 90^{\circ})x, \tag{2}$$

will be parallel to the non-random array. If the points lie in a line, then the perpendicular distances of these points from this line will be the same. Substitution of the coordinates into the relation,

$$\delta_i = y_i - \tan (\psi - 90^{\circ})x_i, \tag{3}$$

produces δ_i which are proportional to the perpendicular distances from the line. A histogram is made of the values of δ_i. The histogram maximum is located. The number of entries in the maximum is the number of colinear points and these points lie along the line,

$$y = \tan (\psi - 90^{\circ})x + \delta(\text{histogram max}). \tag{4}$$

The points which fall near this line are identified as the probable mines in the mine field. We can take these points as a subset and confirm the metric spacing and fill in the locations of the missing mines.

The image in Figure 3.3-1 and the coordinate data in Table 3.3-1 are used as an illustrative example. A minefield with a spacing of $\sqrt{5}$ units was introduced at a slope of 0.50. Ten mine detections and eight false alarms are shown. The total number, N, of detections is 18. The wavelength is chosen to be $2\sqrt{5}$ to produce a main broadside lobe. The received far field power at azimuth angle, ϕ, is found by

$$\phi(\psi) = \left| \sum_{j=1}^{N} \cos\left[\frac{\pi}{\sqrt{5}} (x_j \cos \psi + y_j \sin \psi)\right] \right.$$
$$\left. + i \sin\left[\frac{\pi}{\sqrt{5}} (x_j \cos \psi + y_j \sin \psi)\right] \right|^2 \tag{5}$$

Table 3.3-2 shows $\phi(\psi)$ for each 5° interval using the x_j, y_j of Table 3.3-1.

It is not difficult to see that a main lobe exists somewhere between $115°$ and $120°$ in Table 3.3-2. Cubic interpolation indicates that the linear array has a direction, $\phi - 90° = \sim27°$. The probability of a received power of 89.3 or greater is 0.007 for a Rayleigh distribution with an average of 18. Changing the wavelength to be $\sqrt{5}$, the expected array spacing, also results in an improbably large received power at $27°$ as would be expected if the mean mine spacing of $\sqrt{5}$ existed.

The histogram of δ values in Figure 3.3-2 clearly shows that 10 of these spots fall in a line parallel to the expected array direction so that the spots are identified. Using these identified spots, one can find the least squares best fit to these points resulting in the best fit line of the field. Finally, the distance, s, of each of these 10 spots along the best fit line can be calculated. Location of the missing mines can now be done by choosing any spot as origin of the line and incrementing by the expected mean spacing, d, by integer multiples.

One can expect that the rms fluctuation of received power for a Rayleight distribution will be equal to the mean value of received power. Thus, if there are n mine detections and m false alarms, one can expect a main lobe power of n^2 and a fluctuation of $\pm m$. An improbable power could be recognized if $n^2 > 4$ m or $n > 2\sqrt{m}$. If 10^4 false alarms were present, for instance, then only 200 mine detections would be required if the pattern were to be evident. In the illustration shown in Figure 3.3-1, m = 8 and n = 10 resulting in,

$$10 > 2\sqrt{8} \qquad \text{or} \qquad 10 > 6,$$

so that detection was easily accomplished.

The algorithm requires exploration against real backgrounds and should be evaluated against the capability of human vision. Real backgrounds are not likely to be random but may contain arrays – such
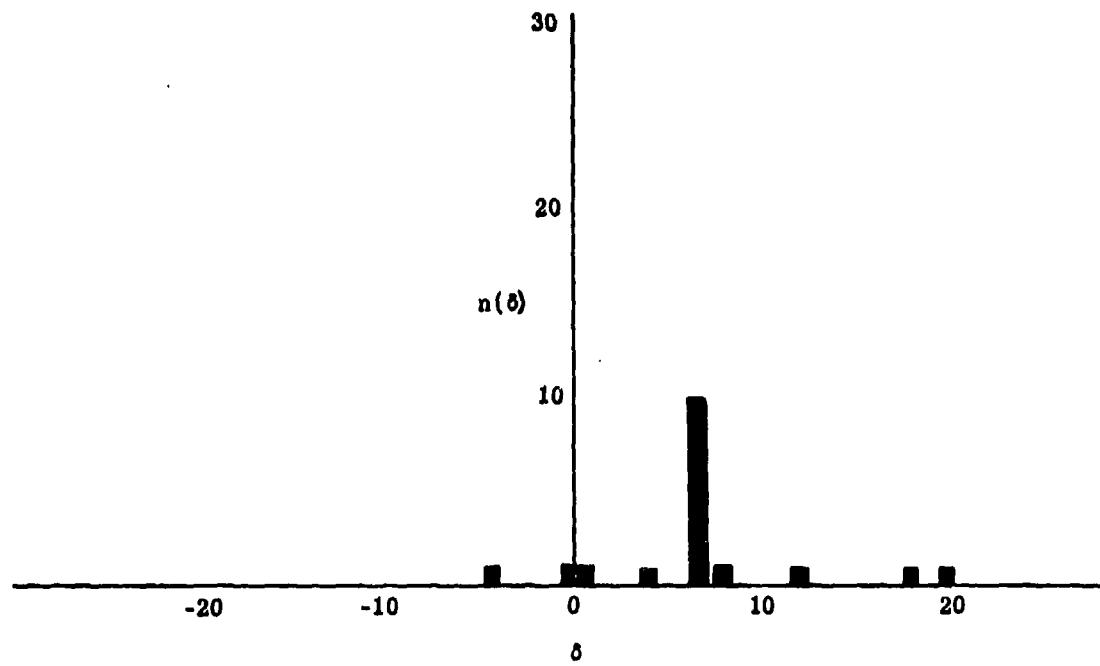
FIGURE 3.3-2. HISTOGRAM OF δ

TABLE 3.3-2
RECEIVED POWER FROM ANTENNA FARM

ψ Degrees	Φ	ψ Degrees	Φ
0	0.03	105	13.40
5	0.79	110	4.08
10	0.12	115	89.30
15	2.92	120	70.39
20	9.86	125	1.99
25	12.32	130	20.34
30	3.53	135	35.05
35	2.40	140	6.66
40	5.86	145	4.71
45	22.47	150	22.94
50	20.43	155	16.24
55	12.89	160	20.61
60	16.00	165	49.56
65	7.95	170	16.81
70	2.66	175	2.99
75	10.96	180	0.03
80	14.52		
85	1.02		
90	19.89		
100	2.89		

as fence posts, hay stacks, and orchard tree stumps - which might disrupt this algorithm.

This algorithm could easily be executed with great speed on a simple dedicated microprocessor. The trigonometric values would be contained in ROM for one degree intervals from 0 to 90°. Interpolation would suffice if greater resolution is needed. Addition, subtraction, multiplication and division are the only operations required except for one square root operation to determine the probable power criterion.

3.4 RECOGNITION OF SMALL ARRAYS

Under some conditions, pattern recognition must be performed on a relatively limited number of mines. High resolution imagery might be obtained at the expense of flying at low altitude and thus restricting the swath width which can be observed in a single pass. In other cases, the emphasis might be on finding gaps in a larger field which would provide a gateway without mine clearing.

The fact that minefields are placed in some reasonably ordered fashion in accordance with military purpose allows one to discriminate between real and counterfeit mines without requiring the recording of high spatial frequencies in the image. If the image of the minefield results in a discernible array of detectable spots of about the right size, those detectable spots which seem to fit in an array will be called mines and those that do not will be called counterfeits. Some criterion is needed to establish the number of unidentified spots that must be detected in order to perceive the array. For this example, the assumption is made that at least 10 out of a group of 20 mines must be detected in order to perceive the array. For this example, the assumption is made that at least 10 out of a group of 20 mines must be detected in order to perceive the pattern. Although a complete minefield may contain many more mines, it is

assumed that there could be gaps in the field which could provide a
gateway without mine clearing activity. A gap of 20 mines could be
such a gateway or could indicate the termination of one field and
the beginning of another.

By requiring detection (but not recognition) of at least 10 out
of 20 mines to perceive the pattern, the probability of detection of
that part of the field becomes a function of the stability of detect-
ing a single unresolved spot as shown in Table 3.4-1.

The relationship between probability of detection of individual
mines and probability of identification of complete minefields, as
shown here, is a preliminary and arbitrary assumption. It is recom-
mended that during the continuation of this project, additional study
be placed on establishing a firm foundation for modeling this
relationship.

TABLE 3.4-1
RELATION BETWEEN DETECTION OF
INDIVIDUAL MINE AND DETECTION
OF MINE PATTERN

p (individual)	P (pattern)
0.1	7×10^{-6}
0.2	0.0026
0.3	0.048
0.4	0.245
0.5	0.588
0.6	0.872
0.7	0.983
0.8	0.999

4
SENSORS

In this section, each of the generic types of sensors identified in Section 2 is discussed. The general technical characteristics of each generic type are presented, along with a discussion of its inherent advantages and disadvantages. This discussion leads to a definition of the operational role the sensor might be expected to play in the minefield detection process and to resulting recommendations for further investigation of the sensor type. For those sensors considered to be potentially suitable for use, a technical characterization of a representative system is then given which may be used for operational modeling.

4.1 AERIAL PHOTOGRAPHY

4.1.1 SENSOR CAPABILITIES AND LIMITATIONS

Aerial photography provides a technique of mine detection which is fully developed and has for many years played a major role in reconnaissance and surveillance missions of the Armed Forces. Systems already in inventory are capable of being used for this function without special adaptation of camera equipment, but the vulnerability, target accessibility, and response time of the method requires careful consideration.

Aerial photography has the major advantage of providing high resolution imagery, which is an important consideration for the mine detection application, where objects of relatively small dimensions must be detected and identified. The high resolution and metric accuracy of the image also aid accurate location of the target.

The spectral range of available films extends over the visible and near infrared regions of the spectrum, so that some selectivity of optimum spectral band is available. In particular, discrimination

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of mines against background vegetation would be optimized in the near infrared region.

Mines are best detected by vertical viewing with aerial photography, since this minimizes obscuration by atmospheric path radiance or by terrain obstacles, standing vegetation, etc. However, vertical viewing requires the aerial platform to fly along routes which may be close to the FEBA and vulnerable to enemy fire, so that vulnerability must be traded off against the advantages of aerial photography.

Aerial photography can be collected in daylight during clear, hazy, or partly cloudy weather, or in cloudy weather at low altitudes. Without some form of illumination, it is not adaptable to nighttime use.

Another major consideration is the rapidity of response of aerial camera systems to the need for data. The time from target contact to delivery of minefield location information includes the time for flyover, landing, film development, and photointerpretation. These conventional methods of data collection, interpretation, and delivery will be inadequate to meet the response requirements of several of the scenarios being considered in this study. The use of near-real-time film development and air-to-ground data links may be called for to meet these critical requirements for timeliness.

The technical example given in Section 4.1.3 assumes the use of a KA-45A or KA-91A camera in an RF-46 aircraft. For this combination, area coverage is approximately as given below

Camera	Swath (at 1 km altitude)	Rate of Area Coverage (at 1 km altitude)
KA-45A	748 m	0.5 sq. km/sec
KA-91A	1044 m	0.7 sq. km/sec

4.1.2 RECOMMENDATIONS

Because of its current widespread use and availability and its
potential for reliable mine detection under appropriate circum-
stances, it is recommended that aerial photography be given continu-
ing consideration in the present study. Emphasis should be placed
on determining the technical performance of high resolution cameras
in the mine detection operation, and on assessing the operational
usefulness of the technique in light of the vulnerability and timeli-
ness constraints mentioned above. A technical example is included
in Section 4.1.3 as a basis for evaluating operational usefulness.

A study should be made of aerial camera/platform combinations
which are currently in use or at some stage of development for the
Armed Services, so that sensor/platform systems most likely to be
applicable to the mine detection problem can be selected for further
consideration.

Most mine detection systems inherently detect only individual
mines, and these may be imbedded in clutter, so that reliable iden-
tification of the individual mines may be difficult. The ability to
recognize minefields is enhanced by being able to observe and iden-
tify the regular pattern in which mines are laid. Two general
approaches to pattern recognition should be investigated and com-
pared: (1) human photointerpretation and (2) computer-based pattern
recognition algorithms.

4.1.3 TECHNICAL EXAMPLE

An analysis has been made of the probability of detection of in-
dividual mines and complete minefields using aerial cameras carried
by the RF-4C aircraft. This example provides data which can be used
in operational analyses of the effectiveness of aerial cameras in
the minefield detection mission. The detailed analysis of the system
on which this example is based is presented in Appendix A.

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ERIM

Data are provided here on two types of aerial cameras, the KA-45A
and the KA-91A. The camera specifications are as follows:

1. Camera: KA-45A
    Field of View: 41° x 41°
    AWAR, 1000/1: 45 lp/mm static test with pan-X
    Lens Focal Length: 150 mm

2. Camera: KA-91A
    Field-of-View: 14° x 60°
    AWAR, 100/1: 50 lp/mm static test with pan-X
    Lens Focal Length: 460 mm

Both cameras are assumed to operate with a Wratten 25 filter
using IR 2424 film. The near infrared band was chosen to assure that
a reliable contrast would exist between most terrains and the mine as
well as to provide some penetration of possible haze at the time of
operation. Both cameras operate with the center of the frame in the
nadir direction.

4.1.3.1 Assumptions

The probability of detection data are based on the following
assumptions:

-   Reflectance of the mine is 0.05 and reflectance of the back-
    ground is 0.20.

-   The probability of detection of an individual mine is a func-
    tion of both system resolution, and contrast between target
    and background. The probability of detection as a function
    of contrast is derived from the results of visual detection
    of targets in visual range experiments reported in
    Reference 2.

- Two atmospheric conditions are assumed: (1) clear atmosphere and (2) medium haze.

- Two magnitudes of clutter are assumed, as described next.

Modulations of radiance patterns in natural terrain due to the terrain texture can produce modulations at low spatial frequencies which resemble those of a single mine against a terrain background. Thus, if only low spatial frequency components appear in the image, these naturally occurring spots that make up the terrain texture could appear to be counterfeit mines. The degree or severity of clutter can be quantified by stating the minimum spatial frequency component which must be perceived in the image in order to distinguish between naturally occurring counterfeits and the real mine without excessive false alarms.

Thus, a low clutter condition is defined here as that clutter condition which requires the perception of image modulation up to a minimum spatial frequency of 1/2 cycle/(mine diameter). A medium clutter condition is defined as that clutter condition which requires the perception of image modulation up to a minimum spatial frequency of 2 cycles/(mine diameter).

4.1.3.2 Probability of Detection

The results of the computations for two haze conditions and for two angles, nadir and 30 deg. from nadir, are given in Figure 4.1-1 and 4.1-2. The results show that for 20 deg. off axis (frame edge), detection is not enough different to be plotted for the KA-45A. The KA-91A detection probability deteriorates from nadir to 30 deg. of nadir. Although atmospheric haze at 30 deg. slant angle is partially responsible, an important factor is the foreshortening of the target in one dimension and the greater range to the target so that the required minimum spatial frequency increases as $[\sec \theta]^{1.5}$. All oblique photography will tend to perform more poorly because of these effects.
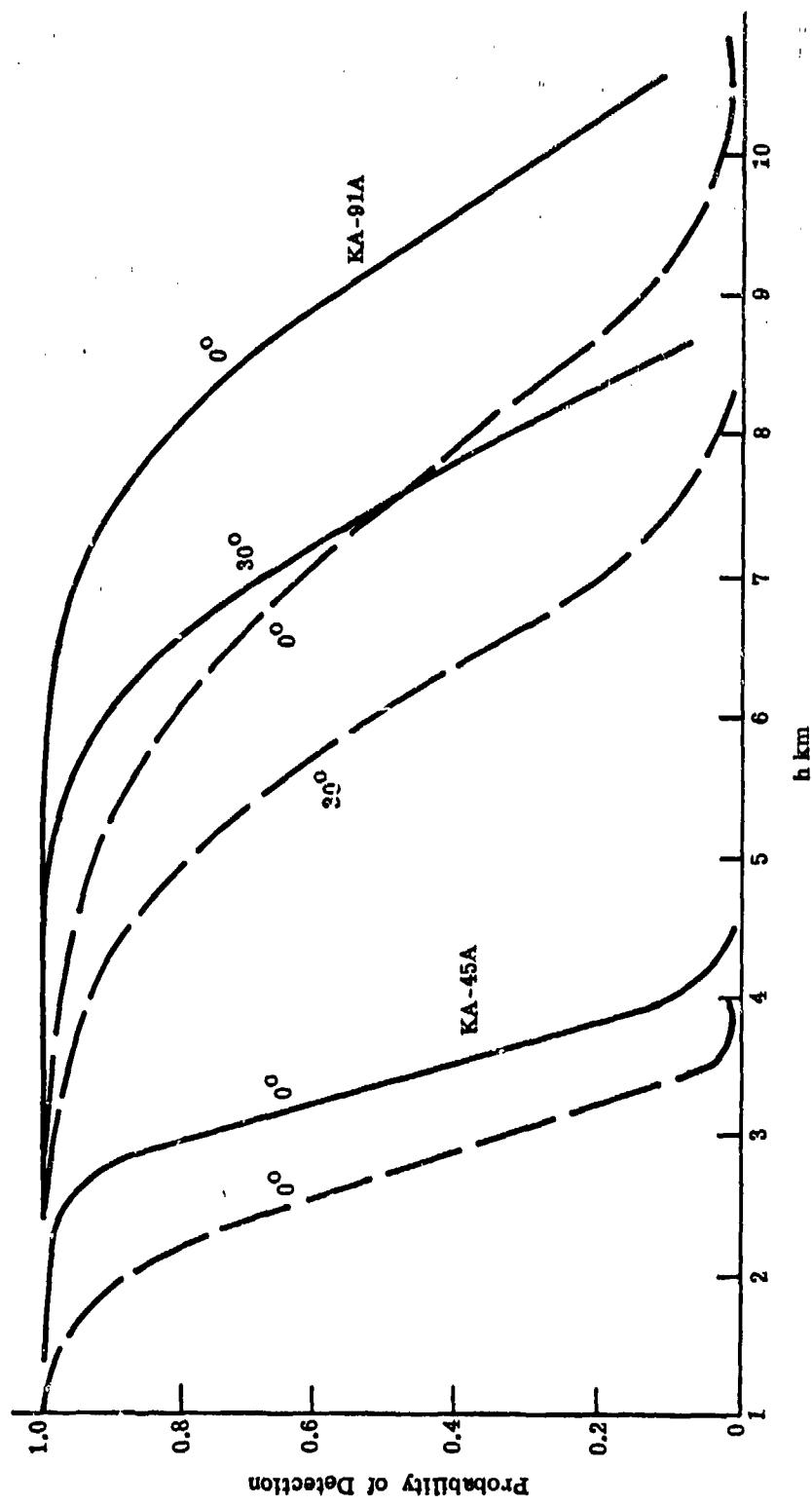
FIGURE 4.1-1. LOW CLUTTER PROBABILITY OF DETECTION

Solid Line - Clear Atmosphere
Dashed Line - Medium Haze
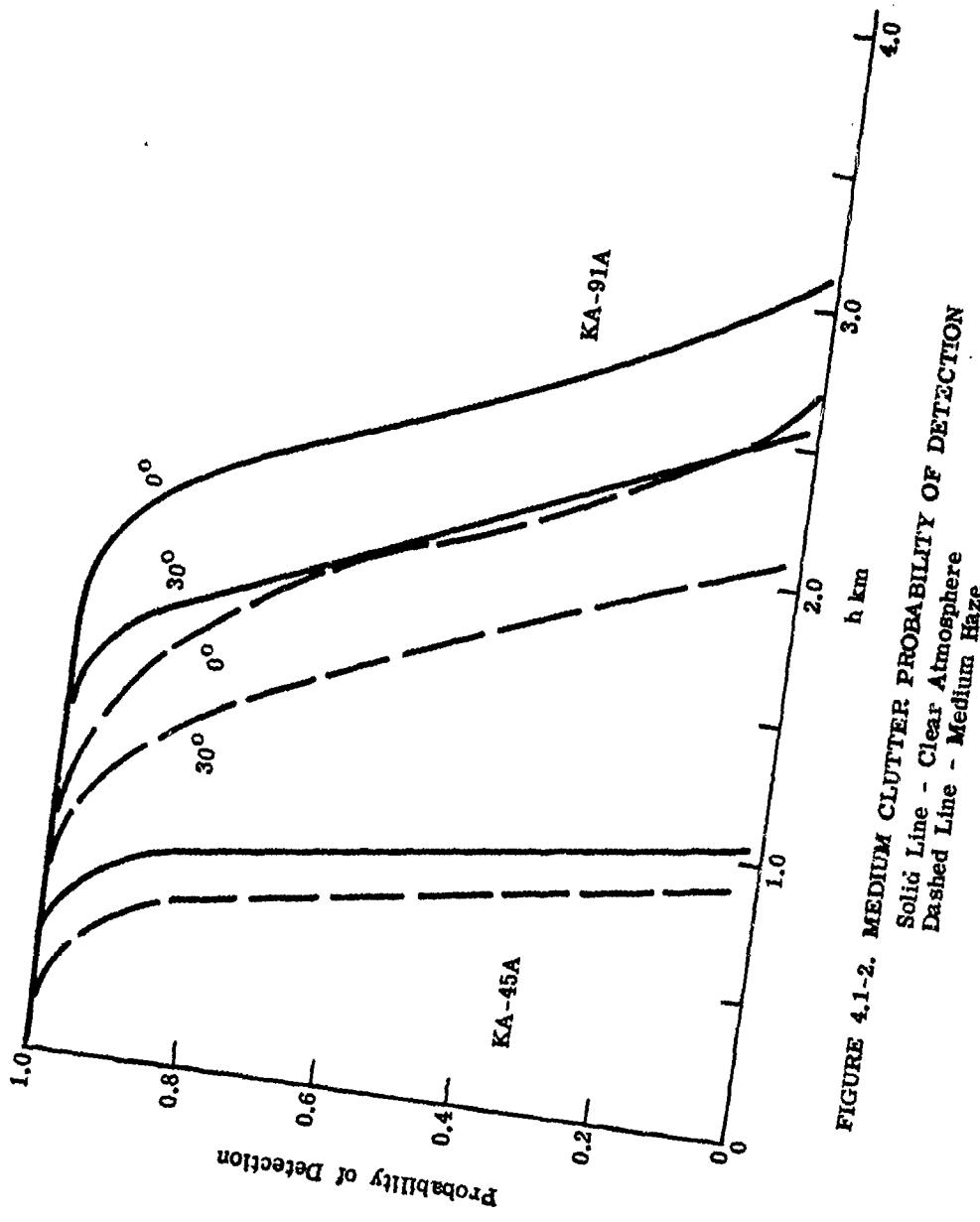
FIGURE 4.1-2. MEDIUM CLUTTER PROBABILITY OF DETECTION

Solid Line - Clear Atmosphere
Dashed Line - Medium Haze

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4.1.3.3 Detection of a Minefield by Pattern

The detection probabilities shown in Figures 4.1-1 and 4.1-2 are for detection and recognition of a single, isolated mine given line-of-sight to the mine. For the low clutter condition, a detection of any small spot on the film having about the right size leads to recognition. In the medium clutter case, a detection of a small spot on the film could be the detection of a counterfeit -- such as a small depression containing water, a shadow from a rock or small bush, or a piece of military junk left on the ground. The imaging of higher spatial frequencies is needed to distinguish between these counterfeits and the real mine on a one-by-one basis.

The use of pattern recognition techniques for identifying mine-fields has been discussed in Section 3. For use in the technical example for aerial photography, the minefield recognition procedure described in Section 3.4 may be used. That procedure covers the case where at least 10 mines out of a group of 20 mines must be detected to perceive the minefield pattern.

4.1.3.4 Line of Sight

The calculations above result in the conditional probability of single mine detection given line of sight to the mine. It is also necessary to consider the probability of line of sight to the mine over the type of terrain to be considered. The product of the probability of line of sight to the mine and the conditional probability of single mine detection is the probability of mine detection for that terrain type.

Reproductions of aerial photographs of six scenarios in West Germany [3] were examined for estimating the probability of line of sight to mines. If one considers that the probable location of mine-fields will be somewhere in trafficable areas, and not in forested sections, then the probability of line of sight to ground level

should be close to unity for trafficable areas. Where tall trees and buildings occur, the trafficability is quite poor. In addition, if rapid minelaying is accomplished from ground vehicles, the ground vehicle will require trafficability for its mission. A minefield that is placed in a location that cannot support traffic for other reasons might not be detected but for practical military purposes, the minefield might as well not exist anyway. For nadir and 30 deg. from nadir, large obstructions to trafficable areas are rare.

It is likely that surface mines laid in mature crops will not be observable at more than 10 deg. from nadir. During the Summer, half of the trafficable land may contain mature crops. For these assumptions, the probability that the mine will not be obscured by the crop will be 0.59 for an image from the KA-45A camera and 0.65 for the KA-91A.

4.2 RADAR

Radar is the only long-range, all-weather sensor available for the detection of remote minefields and minelaying operations. Radar detection of surface mines can occur in two ways. First, if a radar has very fine resolution, the background clutter may be low enough so that individual mines will be visible in the radar maps. Second, it may be possible to detect the presence of a minefield by an increase in the average reflectivity of its background. This detection method would be applicable to radars with poorer resolution. Past analysis indicates that the low cross section of mines makes the reflectivity change small and hard to detect unless the minefield is in an area of below-normal reflectivity.

Other radars which have been considered during the identification and screening of mine detection methods are real aperture imaging radars, moving target indication (MTI) and pulse Doppler radars, near-field microwave radars and non-linear radars.

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Under highly favorable conditions, minefields have been detected in X-band radar imagery; however, radar minefield detection in scenarios typical of Eastern Europe has not been demonstrated. Until radar has shown the capability of detecting remote minefields on terrain similar to Eastern Europe, uncertainties about its utility for this purpose will remain. Consequently, the screening process has resulted in the decision to place high priority in the program on obtaining adequate experimental information on adar capabilities for minefield detection. Under Task III, fl'_nt experiments are being conducted which will provide this ir ormation, and further decisions on the utility of radar must await the availability of this information.

In the first phase of the radar experimental program, minefield arrays are being set up, and data will be collected with ERIM's high resolution Spotlight radar. The objective of the spotlight measurements will be to study (1) the detection of surface and buried mines as a function of radar resolution and (2) inferential detection methods based on differences in average reflectivity between mined and unmined areas. The probability of detection and the probability of false alarm depends on the statistics of the target cross section, noise, clutter and the ratio of the signal power S to the sum of the noise and clutter powers (N + C). Clutter rather than noise is usually the significant factor for a target on the ground. High resolution is important because the clutter power is equal to the average reflectivity of the terrain times the area of a resolution cell.

Mine and minefield detectability depends also on radar frequency and polarization. (An extensive discussion of these subjects with respect to mines and minefields is given in Reference 4.) Areas which are smooth with respect to wavelength, scatter signals specularly. Terrain may appear smooth at L-band and rough at X-band. Foliage penetration is better also at the lower frequencies. Geometric properties of surfaces affect the polarization of a backscattered signal. Rough surfaces tend to depolarize the backscattered

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signal more than smooth. Depolarization caused by volume scattering can also occur if the incident microwave energy can penetrate beneath the surface. A given scene can appear differently for different frequencies and different polarizations. A multi-frequency, multi-polarization can provide extra information over that provided by single frequency, single polarization radars and may enhance the detection probabilities of mines and minefields.

4.2.1 SYNTHETIC APERTURE RADARS

Synthetic aperture radars (SAR's) are fine resolution imaging radars characterized by coherent radar signals, by imaging areas parallel to the direction of travel but offset to the side, and by cross-range resolution independent of range. The primary military application is mapping for surveillance purposes; large areas can bo mapped under most weather conditions in a short period of time.

Strip maps are created by illuminating the ground in range up to tens to hundreds of kilometers and in azimuth by a narrow ram, typically on the order of one degree, and by moving the beam laterally. Fine resolution in range is obtained by using a wide bandwidth signal. Fine resolution in cross-range is obtained by synthesizing antenna apertures whose lengths are proportional to each range, that is, the aperture length to range ratio is constant for all ranges. Resolution, both in range and cross-range is on the order of a few meters, insufficient to detect and identify individual mines but sufficiently fine, perhaps, for recognizing changes in average reflectivity from that existing in mine-free areas.

Moving targets appear on SAR maps as smeared imagery and not in their true locations unless provision is made for operating in an MTI mode. Slowly moving minelaying vehicles can show up in SAR imagery but displaced from their true positions.

Whether or not individual mines can be detected depends on the radar cross section (RCS) of mines and on the reflection characteristics of the background or the signal-to-clutter ratios. Some RCS measurements of TMD-B, M-15, M-19, TM-46, and PM-60 mines have been made in the laboratory at ERIM. Frequencies used were 1.2 and 1.65 GHz (L-band) and both vertical and horizontal polarizations were used. RCS values ranged from about -3 dBsm down to about -40 dBsm (dB relative to one square meter). Typical values are estimated to be about -15 to -20 dBsm for plastic mines. X-band measurements of plastic, metallic and wooden mines were made on a previous contract at ERIM (Ref. 4). Median RCS value for a PM-60 is -23 dBsm. A metallic mine, the M-15, has a much higher median RCS values, -7 dBsm.

The signal-to-clutter ratio (SCR) is given by the equation

$$SCR = \frac{\sigma \cos \theta}{\sigma_o \rho_a \rho_r} \tag{6}$$

where σ is the RCS of the target (mine), θ is the grazing angle, σ_o is the normalized clutter RCS/m^2 and ρ_a and ρ_r are the resolutions in azimuth and range respectively. The following figures are assumed:

$$\sigma = -15 \text{ dBsm}$$
$$\sigma_o = -20 \text{ dB}$$
$$\theta = 10^o$$
$$\rho_a = \rho_r = 1 \text{ m}$$

The SCR is 4.9 dB. Under these conditions, the resolution magnitudes cannot be relaxed substantially. The greatest variable is the clutter RCS. The -20 dB figure is only a nominal one and the σ_o value will vary substantially depending on whether there is ground cover and on the smoothness of the surface [5]. For smooth surfaces such as water or roads, σ_o may be on the order of -30 to -50 dB so that a large SCR can be achieved. The integrated sidelobe energy may limit

the SCR achievable particularly where the average reflectivity surrounding the target is low. On the other hand, mines are more likely to be placed in fields where the σ_o may be on the order of -15 to -20 dB. Further, if the mine RCS is less than -15 dBsm, the SCR would be further degraded. While the expected SCR's are a function of particular radar designs and of particular mines, it is clear that the resolution magnitudes shouldbe on the order of 1 m or better. Although it appears possible to achieve detection of individual mines by decreasing the size of the resolution element, such small elements are generally not used for strip mapping purposes. It seems likely that resolution magnitudes of one or two meters are sufficiently small so that mines will raise the average reflectivity compared to reflectivity of adjacent mine-free areas.

It has been suggested that the minefield with its uniform pattern of mines can be considered to be an illuminated antenna array so that an array factor is imparted to the reflected energy. The concept is an attractive one, but it is unlikely that usable gains can be achieved consistently. Heuristically, the argument against the concept is as follows. The radar wavelength is a fraction of the spacings between mines (on the order of 4 to 6 meters), even if L-band is being used. While the mine spacings are reasonably uniform, variations occur, both intentionally and unintentionally. These variations can be and are significant fractions of a wavelength. Further, the mines will not be illuminated uniformly by a radar, particularly in phase, so that the likelihood is small of the radar returns from the individual mines arriving in phase and enhancing the signal at the radar receiver.

The Spotlight radar is a form of synthetic aperture radar which can produce very fine resolution imagery. The radar provides several unique characteristics which have high probability of application to the problem of remote minefield detection.

This system is the finest resolution airborne radar available. This fine resolution characteristic means that mines, whose radar cross section is quite small, will be in the smallest possible clutter patch and thus will have increased probability of detection from the signal-to-clutter standpoint.

The high angular diversity available with Spotlight radar (up to 90° of azimuth angle swept on a single pass by a target scene) increases the probability of detection in two ways. First, the specular characteristics of reflection of some mines puts a premium on a sensor which will view at least one facet of the mine on every pass. For rectangular mines such as the TMD-B, the 90° change in aspect guarantees that at least one dihedral reflector between mine and ground will be illuminated on each pass. Second, the angular diversity decreases the chance that any mine signature, whatever its specular characteristics, will be hidden by a topographic, vegetative, or cultural shadowing object. Once again, the 90° variation in aspect makes the job of hiding objects from the radar system, either purposely or accidentally, much more difficult. In fact, in the "safest" case where the radar would operate parallel to the FEBA and look into enemy-held territory, mines hidden from the radar would have to be placed close behind moderately large objects, a location less likely to be a threat to vehicles or personnel penetrating the FEBA from the friendly side.

Depression angles available from the Spotlight radar system vary from near grazing to near vertical (6° to 70°). The low depression angles would be characteristic of both a moderate altitude long stand-off range system which escapes the near FEBA anti-aircraft threat entirely or a low altitude low exposure penetrator. The higher depression angles would be used with high flying reconnaissance aircraft which overfly the SAM threat. The moderate depression angle range would be used with pre-hostility non-penetrating radar systems which might perform across-the-border surveillance. In

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addition, the large variability in depression angle allows one to
investigate several scenarios which might increase minefield detecta-
bility. In relatively open areas, where shadowing is at a minimum,
detectability may be enhanced by operating at low depression angles
to decrease background reflectivity with respect to surface deployed
mines and thus increase their signal-to-clutter ratio. Additionally,
at finest resolution, low depression angles accentuate shadows. On
the other hand, the low mine silhouettes will prevent the casting of
large shadows. At higher depression angles, the surface reflections
increase. The likelihood of detection of surface disturbances caused
by manual or machine minelaying would thus increase at these high
depression angles.

The all weather, day-night capability of radar systems is an ob-
vious advantage in that it takes away the enemy ability to hide his
mine-laying activity under cover of clouds or darkness. Combined
with the very fine resolution of the Spotlight system which might
allow identification of minelaying equipment, this anytime imaging
capability may provide the best minefield detection potential of any
radar candidate sensor.

If tests conducted with the Spotlight radar and specialized proc-
essing of the data are sufficiently positive, the utilization of syn-
thetic aperture radar should be further investigated. For this pur-
pose, tests with ERIM's X-L radar would provide useful information
on foliage and soil penetration. The X-L radar has four receiver
channels which provide parallel- and cross-polarized data at two fre-
quencies. The multiple channels provide data to test ratioing and
other special processing techniques. The swath width of the X-L
radar is about 6 km. These tests would enable us to draw conclusions
about the utility for minefield detection of current and future radar
systems, such as the AN/APD-10 and the TR-1 SAR.

4.2.2 MTI AND PULSE DOPPLER RADARS

MTI and pulse Doppler radars are generally designed to detect, locate, and occasionally identify moving vehicles or men. The ability to detect motion is primarily used as a means for screening targets from the undesirable background. These radars can measure range and angle but with relatively large resolution values. Range resolution on the order of 8 to 16 m is typical while angular resolution often is not better than one degree. The lack of fine range and angular resolution capabilities preclude the detection of individual mines with MTI or pulse Doppler radars. Table 4.2-1 lists representative MTI and pulse Doppler radars presently operational or under development.

The possibility exists for observing minelaying and/or mine removing operations in any of the scenarios. The absence of traffic (men or vehicles) across a minefield can lead to suspicion about its presence provided a minefield is in place for extended time periods as in the defense minefield scenario, Scenario D. Verification of minefield presence would be required in all cases.

Laying surface minefields involves the use of a tracked or wheeled vehicle and several men. During a minelaying operation, the vehicle can be expected to move slowly, typically, 7 km/hr or so, along the length of a minefield. Men can be expected to move not only in the same direction as the vehicle but laterally as well in order to spread out mines in several rows. While motion patterns cannot always be expected to be the same, there is likely to be some regularity in vehicular and personnel motions. The low speeds and the regular motions combined with information on enemy concentrations and terrain characteristics can aid in supporting the inference that a minefield is being laid.

From a technical standpoint, there is no question that vehicles have a sufficiently large RCS to be detected. The main question

TABLE 4.2-1
LIST OF REPRESENTATIVE MTI AND PULSE DOPPLER RADARS

Sensor	Expected IOC	Platform
SOTAS (Standoff Target Acquisition System)	1983	UH-60 Helicopter
AN/PPS-5A, Pulse Doppler	Operational	1/4 Ton Truck, Tripod
AN/PPS-15	Operational	Handheld, Tripod or Pintle Mounted
AN/TPS-21 and AN/TPS-33 Pulse Doppler Radars	Operational	Tripod

concerning detectability has to do with the magnitude of the radial
component of vehicular velocity with respect to a radar since mine-
laying vehicles move slowly and MTI and pulse Doppler radars have a
minimum velocity threshold below which moving targets are in clutter
and cannot be detected. A chart which can be used to determine the
horizontal field of view over which a target (vehicle or man) can be
detected is shown in Figure 4.2-1. Let v be the target speed and v_{TH}
the radar's velocity threshold. The radial component of velocity
cos θ towards (or away from) the direction of the radar must exceed
the threshold velocity for the target to be detected. That is,

$$v \cos \theta \geq v_{TH} \tag{7}$$

and,

$$\theta \geq \cos^{-1} (v_{TH}/v) \tag{8}$$

This relationship between the azimuth angle θ, and the velocity ratio
is plotted in Figure 4.2-1. Assume, for example, that the target
velocity is 7 km/hr and the radar's threshold velocity is 2.8 km/hr.
The ratio is 2.8/7 or 0.4 and the target can be detected if the radar
is pointed at the target anywhere over the aspect angles depicted by
the lined zones. Detection occurs over approximately two-thirds of
all aspects. If the threshold velocity is doubled to 5.6 km/hr, the
target would still be detected over approximately 40 percent of all
aspect angles. If the threshold velocity remains at 2.8 km/hr and
the target velocity is 4.8 km/hr, about a man's walking speed, the
v_{TH}/v ratio is 0.58 and the man would be detected at aspects between
307 to 53° and 127 to 233°. Even slowly moving targets would be de-
tected over approximately half of all aspects. It is well to note
that the detection ranges for men will be less than for vehicles be-
cause of the farmer's lower RCS's. Threshold velocities may be
higher for men for the same reason.

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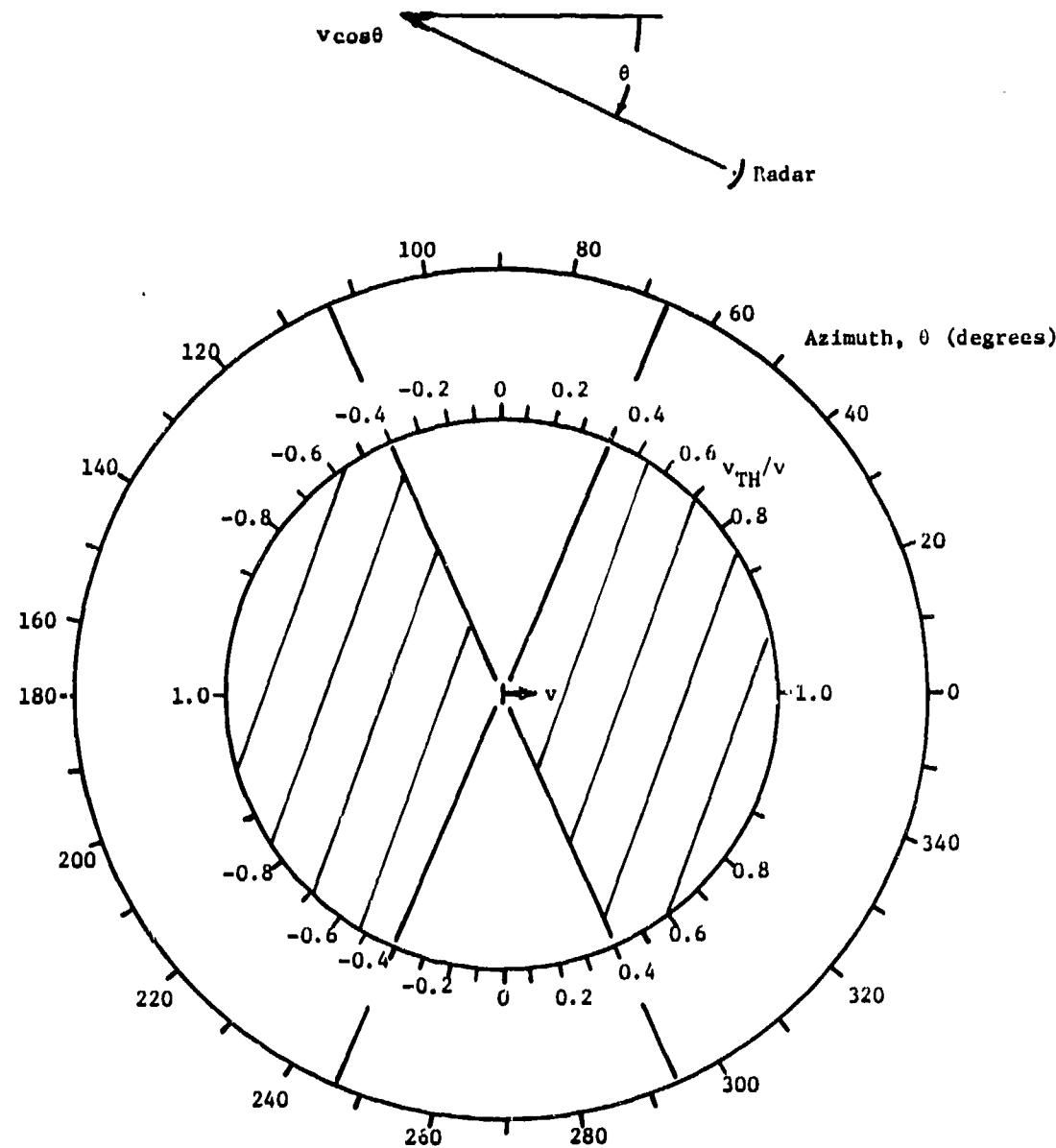
FIGURE 4.2-1. MTI AND PULSE DOPPLER RADARS VIEWING ASPECTS
AGAINST SLOWLY MOVING TARGETS

v_{TH} is minimum detectable velocity $\theta \geq \cos^{-1} (v_{TH}/v)$

Lined zones indicate viewing aspects for $v_{TH}/v = 2.8/7$

The ability to detect either or both minelaying vehicles or men is thus dependent upon the scenario and the possible radar locations with respect to the minefields. The effect of scenario dependence is illustrated in Figures 4.2-2 and 4.2-3. In both these figures, a minelaying vehicle is assumed to be moving at 7 km/hr along the length of a minefield. The minimum velocity threshold for the radar is assumed to be 2.8 km/hr as in Figure 4.2-1. These figures clearly indicate that even if a moving vehicle can be detected by a radar over fairly wide areas and angles, not all these areas will be accessible to friendly troops. In Figure 4.2-2, a second zone is shown where men moving normal to the vehicle's direction of motion can be detected by a radar. (For a PPS-5A, v_{TH} is about 1.6 km/hr and $\theta = 71^{\circ}$ for $v_{TH} = 1.6/4.83$.) In this case, those zones available to a radar for observation of minelaying men are even more restricted than for the vehicle.

MTI and pulse Doppler radars can be used only in an inferential manner to detect the laying of minefields. The key question is not whether or not men and vehicles can be depicted; the key question is how distinctive are minelaying motions and their patterns as discerned by MTI and pulse Doppler radars compared to other motions likely to be encountered on a battlefield. That there may be some distinctive patterns is likely since Warsaw pact forces use formalized procedures in laying mines as in other operations.

Unless motion patterns are unique, the best one can hope for is that motion detecting radar outputs can be used only for cueing purposes.

Uniqueness of minelaying motions can be confirmed only through observations of actual minelaying operations. If minelaying is practiced by Warsaw pact forces during any of their extended maneuvers, it would be desirable to use a radar such as SOTAS to record on tape a lengthy history of the maneuvers. These tape recordings can then
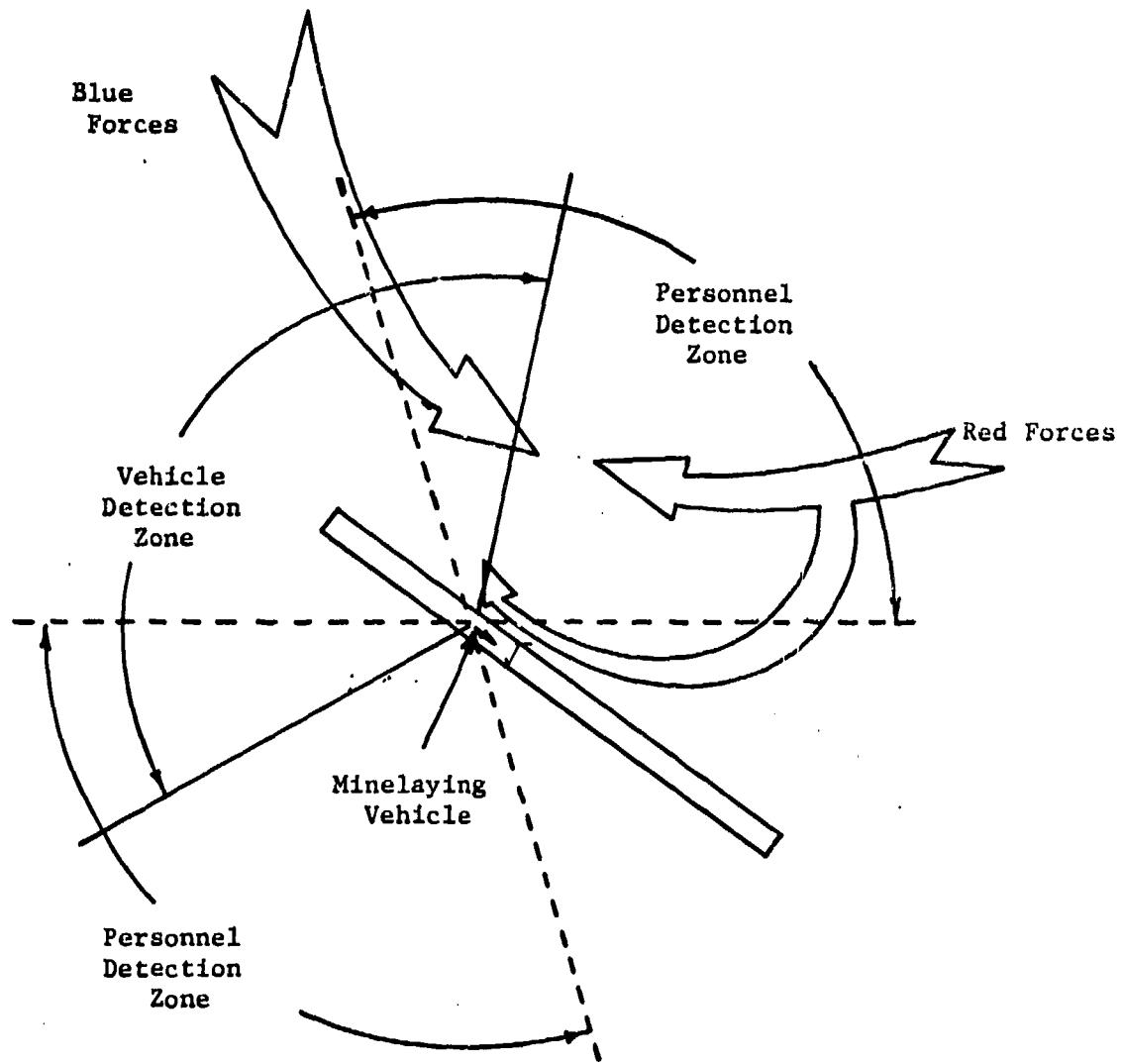
FIGURE 4.2-2. MOTION DETECTION BY MTI AND PULSE DOPPLER RADARS IN SCENARIO A, PROTECTION OF EXPOSED FLANK

Minelaying personnel assumed to be moving normal to vehicular motion.

Vehicle Detection
Zones

Minelaying Vehicle

Blue Forces

Red Forces

Minefield
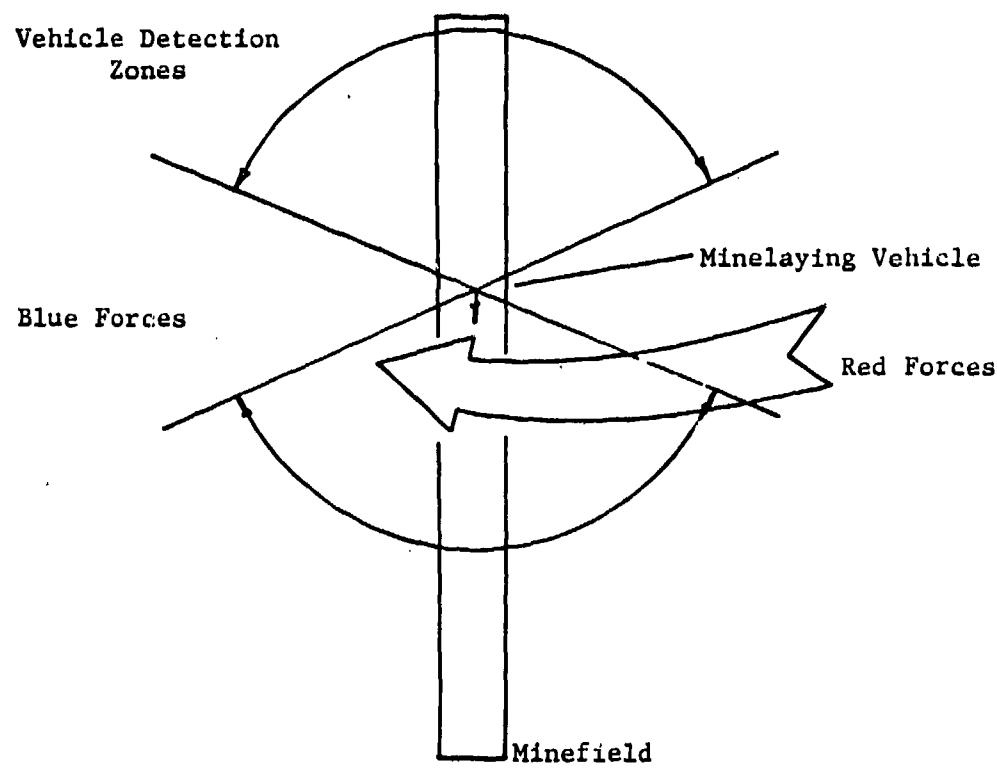
FIGURE 4.2-3. MOTION DETECTION BY MTI AND PULSE DOPPLER RADARS
IN SCENARIO B, PROTECTION OF SHOULDERS DURING BREAKTHROUGH

be studied at leisure to determine if any particular motions can be uniquely identified with particular functions.

Operational analyses of MTI and pulse Doppler radar are not recommended at this time.

4.2.3 REAL APERTURE IMAGING RADARS

Real aperture radars obtain fine resolution imagery by using narrow antenna patterns and short ranges. To achieve imagery with small pixel sizes, such radars performance must operate at high radio frequencies if antenna dimensions are to be kept to a reasonable size. Airport radars used for monitoring ground traffic are one example of real aperture imaging radars. Such radars often operate in the K_u or K_a bands.

As for SAR's, it may be possible to detect individual mines providing the mine RCS is large enough with respect to the clutter within a resolution element. Beamwidths at millimeter wave frequencies for three aperture sizes are illustrated in Figure 4.2-4. For a two or three m aperture, beamwidth does not change rapidly as frequency is increased beyond about 150 GHz. Increasing the aperture from one to two m results in a large change in beamwidth; a much smaller change is effected by increasing the antenna aperture from two to three m. This is so because the rate of change of beamwidth is proportional to the reciprocal of both frequency and antenna aperture.

At 94 Ghz with a 3 m antenna, the beamwidth is 1.3 milliradians. (An antenna of this size would be difficult to construct because of the high mechanical tolerances required.) A mine 1/3 m in diameter would subtend this angle at 256 m range. If a specular reflection exists, an increase in detection range to a kilometer or so is conceivable. The radar beam would have to be scanned in some fashion to cover a reasonable ground swath. High antenna depression angles must be used to overcome terrain and vegetation obscuration effects
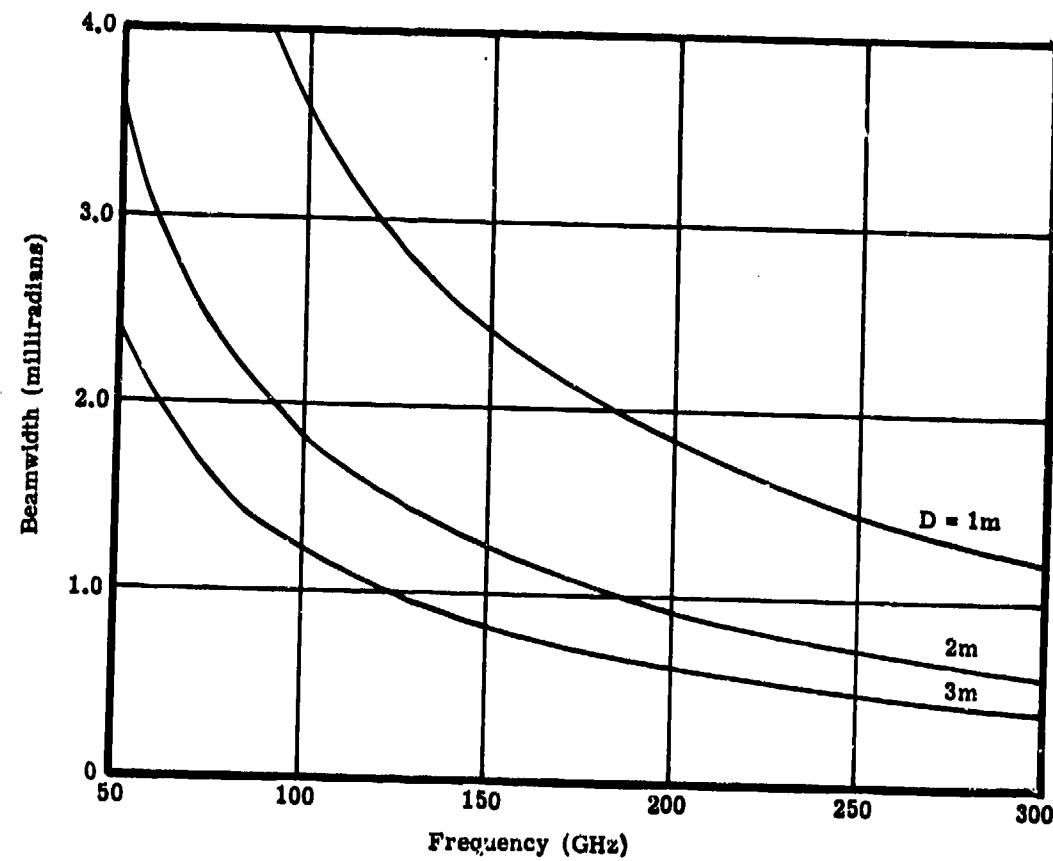
FIGURE 4.2-4. BEAMWIDTH vs FREQUENCY AND ANTENNA DIMENSION
Beamwidth = 1.22 λ/D radians

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so that the use of an aerial platform is implied. Pattern recognition techniques will have to be applied to determine the presence and extent of a minefield. Adverse weather conditions should degrade radar performance less than the performance of electro-optical systems.

While real aperture radar mapping systems exist, these radars do not possess the range independent resolution capability in the cross-track direction and there is no assurance that such systems can detect mines or minefields. If real aperture imaging radars are to be considered seriously for mine and minefield detection, mine RCS at millimeter wave frequencies should be calculated and measured; these RCS values should be compared to clutter values. Mines may exhibit some specularity at these frequencies. If favorable signal-to-clutter ratios can be achieved, real aperture sensor systems should be postulated based on the calculated or measured results and the systems should be subjected to an initial operational analysis.

4.2.4 NEAR FIELD MICROWAVE SYSTEMS

The mine detectors initially developed during World War II to detect buried mines can be thought of as near field radar systems. RF fields are set up by transmitting coils or antennas and these coils are arranged with receiving coils and a detector, often times in a bridge circuit. An object disturbing the fields unbalances the bridge circuit and a detection is indicated. More recent devices have been pulse systems.

The Vehicle Mounted Road Mine Detection System (VMRMDS) is a system currently under development [6]. It supplements the hand-held PRS-7 detector for buried mine detection on roads. A number of antennas arranged in parallel are held 5 cm off the road and the device is pushed 5.4 m in front of a vehicle such as an APC. Each antenna is mounted on a pair of 10 cm casters as that the antenna can tip on

uneven surfaces. The VMRMDS detects buried material down to a preset depth, regardless of the material's magnetic properties. A 16-bit microprocessor inside the vehicle is programmed to discriminate between different materials. Mines can be swept at a rate of 15 km/hr, about thirty times faster than with the PRS-7. Both aural and visual outputs are provided.

The VMRMDS has but a limited capability for detecting buried mines off road because of the need to maintain antenna proximity to the ground. False alarms can be a serious problem also. Any surface mines should be visible to the vehicle driver during the day and with the aid of a night vision device, at night.

Systems such as the VMRMDS cannot be construed to be remote sensing systems unless the vehicle is controlled from a distance. Since remote vehicle control is not practiced and since the system possesses little off-road capability, no further consideration should be given these systems in this study.

4.2.5 NON-LINEAR RADAR SYSTEMS

A non-linear radar system depends on detecting a harmonic of the radiated RF signal. Adjacent metal parts of a metal target have junctions which are non-linear electrically and the third harmonic of the reradiated signals are detected. The METRRA (MEtal Target ReRAdiation) radars are of this type. These radars, both conventional and synthetic aperture, have been tested extensively against a variety of targets including surface minefields. A few mines were detected in a test in Arizona by the METRRA SAR.

These radars are characterized by low frequency (VHF band), by high transmitter powers and large antennas. Thermal noise limits their range capabilities to less than one kilometer. Plastic mines with non-metallic fuzes possess no metal junctions and would not be detected. An advantage possessed by non-linear radars is the low

background clutter. On the other hand, there is a false alarm problem in that this type of radar cannot distinguish between metal debris and minefields.

Only limited data exist on the harmonic RCS of mines. Such measurements should be made if further work is to be performed on assessing these systems technically.

4.3 ELECTRO-OPTICAL SENSORS

Electro-optical sensors take on many forms and can be categorized in many different ways. The categorization chosen here is an arbitrary one but all electro-optical sensors which have potential for mine and minefield detection are included.

4.3.1 PASSIVE INFRARED SENSORS

Passive infrared sensors may take on the form of single detector line scanners or multiple detector, multiple line scanners such as FLIR's. These devices depend on detecting temperature differences or contrast which arise from the thermal characteristics and state of a target and the background or from reflectance differences. Tests have been run with passive scanners, FLIR's and hand-held thermal viewers to determine their capabilities in detecting buried mines [7, 8, 9]. The test results have yielded reasonable detection probabilities under favorable environmental conditions but have on many occasions yielded high false alarm rates. Detection probability is highly variable depending on such conditions as soil moisture, ground cover, time of day, wind, and thermal history. For example, buried mine detection is poor when the soil is saturated.

These same factors will affect how well surface mines can be detected. For a given set of conditions, detection probability can be predicted, but under field conditions, good predictions cannot be consistently made because of the large number of variables involved.

Paints used on mines have reflectance characteristics similar to that of vegetation so that unless there is some thermal difference between mines and their backgrounds, surface mines will be difficult to detect. The thermal mass of either plastic or metallic mines is not large so that temperature differences between mines and their surroundings can occur most often when mines have been distributed just after storage or shortly after sunrise and before sunset.

Passive sensors do not work well in all weather conditions; cloud cover as well as fog and rain can seriously degrade their performance. As in the case of aerial cameras, lines of sight to surface mines can be obscured by both gross and small terrain features and by man-made objects. Ground-based sensors will be greatly restricted in range by obscuration as described in Section 4.3.4. The AN/PAS-7, a hand-held thermal viewer whose resolution capability is 2 mr could resolve a mine on a flat surface at 67 meters but only at a range of 32 meters if vegetation surrounding the mine is as tall as the mine. It is assumed that there is sufficient contrast between the mine and the background.

Airborne systems have an advantage over ground-based systems in being able to fly over or close to an area to be searched. When the objects to be detected are small, however, the height from which they can be detected by a sensor of given angular resolution is limited. The height limitation in turn restricts the swath width which can be observed in a single pass with a sensor of given angular field of view. Some aspects of this problem are also discussed in Section 4.3.4. Those parts of a minefield seen depend on the flight path and on the particular values of resolution, detection ranges and fields of view.

Minelaying vehicles can be detected by passive infrared sensors but unless minelaying chutes or the mines themselves can be detected, one can only infer the presence of a minefield.

There is no question that mines can be detected by passive infra-
red sensors under some circumstances. On the other hand, there are
many circumstances in which detection will not be possible. Those
sensors which offer a higher potential for working under a wide vari-
ety of conditions should receiver priority in investigation over pas-
sive infrared sensors.

4.3.2 MULTISPECTRAL SENSORS

It has been suggested that passive multispectral sensors operat-
ing in the infrared would have a better ability to detect mines and
to differentiate between mines and false targets than do single spec-
trum infrared scanners. This is undoubtedly correct but the degree
of improvement possible is not known since the capabilities of de-
tecting mines of either type of sensor have not been determined. A
multispectral sensor would be subject to the vagaries of weather and
to problems of obscuration, resolution, field of view and detection
range as is the passive sensor. Experiments performed with a multi-
spectral sensor can provide data useful for validating its own capa-
bilities as well as those for single spectrum scanners.

4.3.3 10.6 μm ACTIVE SCANNER

Active infrared scanners have been experimentally tested for the
purpose of producing imagery which is not so dependent on environ-
mental conditions. The signals produced are dependent on the shape
and reflectance characteristics of the objects being observed and
less on the thermal characteristics. Also, the potential for over-
coming adverse weather conditions is greater for an active scanner
than for a passive one.

With these points in mind, simple active tests were conducted as
a part of this project with a scanner on a roof-top and PM-60 and
TM-46 mines on the ground. Ranges were 287 and 440 ft. Each mine

was illuminated normal to its top surface and the detector field of view (approximately 0.8 mr) was scanned through to obtain a zero bistatic reflection pattern. Measurements were made at both 10.6 and 1.06 μm. A sharp reflection pattern was obtained out to 4 or 5 degrees from the axis of symmetry. The signal was about 100 times (20 dB) stronger than the background signal at 10.6 μm and 10 dB at 1.06 μm.

The narrow reflectance peak indicates that an active electro-optical system would have to be looking essentially straight at a mine to detect it. A first-order calculation was performed to determine the percentage of mines which would be detected from an altitude of 305 m (1000 ft) assuming the following conditions: (1) the specular peak of the mine is ±3 degrees from the mine normal, and (2) the angular orientation distribution of the mines is uniform out to 20 degrees from the normal to the terrain plane. The scanner was assumed to cover ±20 degrees from the nadir. On flat terrain, the calculations indicate that 4.5 percent of the mines would be detected and that on a 20 degree sloped terrain, 2.4 percent would be detected. If one specular peak is assumed to be ±4 degrees in width and the scan angle is ±15 degrees 8.4 percent of the mines would be detected in a flat plane.

Since only a small portion of a minefield can be seen at any instant, it is clear that the flight path flown by the airborne platform is an important factor in discovering the extent of a minefield.

4.3.4 IMAGE INTENSIFIERS

The function of night vision sensors is to provide a capability to conduct field operations at night and during periods of poor visibility. Second generation sensors are currently operational or will soon become so. Work is being conducted on third generation devices.

Application areas for night vision devices include devices for the individual soldiers, night sights for anti-armor missile systems,

night vision for combat vehicles and night vision for pilotage and
fire control of Army aircraft. From the technological standpoint,
these devices include those which use image intensifiers and those
which are thermal detectors and which operate in the near and far
infrared regions. The night vision devices enable soldiers to oper-
ate at night as they would during the day using their eyesight.

The image intensifier devices such as the AN/PVS-4, Night Vision
Sight, Individually Served Weapons, the AN/TVS-5, Night Vision Sight,
Crew Served Weapons, and the AN/PVS-5, Night Vision Goggles are
short-range devices. Typical ranging capability in moonlight is on
the order of 600 to 1000 m for detecting men and up to 2 km for vehi-
cles. In starlight, the ranges are forty to fifty percent shorter.
Their resolution capability is on the order of 0.3 to 0.45 mr. The
Hand-held Thermal Viewer, the AN/PAS-7, has a recognition range of
400 m and a resolution of 2 mr.

Night vision devices are mounted on ground vehicles one to two
meters off the ground or held by men who may be prone, crouching or
standing. If image intensifiers, as currently mounted and used, are
adapted for mine detecting purposes, then the line of sight from a
device to a mine will form a shallow or grazing angle with respect
to the ground. The tendency then is to "see" mines edge on. A sim-
ple sketch and calculation indicate a maximum detection range
(Figure 4.3-1).

Let the night vision device be a height, h, above the ground and
let $\Delta\phi$ be the device's angular resolution. Also let the mine diam-
eter be d_m and its thickness, h_m. For small grazing angles or
values of ϕ close to 90 degrees, and for R >> h, it can be shown that

$$R = h_m/\Delta\phi + \left[(h_m/\Delta\phi)^2 - 4(h^2 - hd_m/\Delta\phi)\right]^{1/2} \qquad (9)$$

Range values have been calculated for the devices listed in
Table 4.3-1. The mine diameter is assumed to be 0.3 m and its height
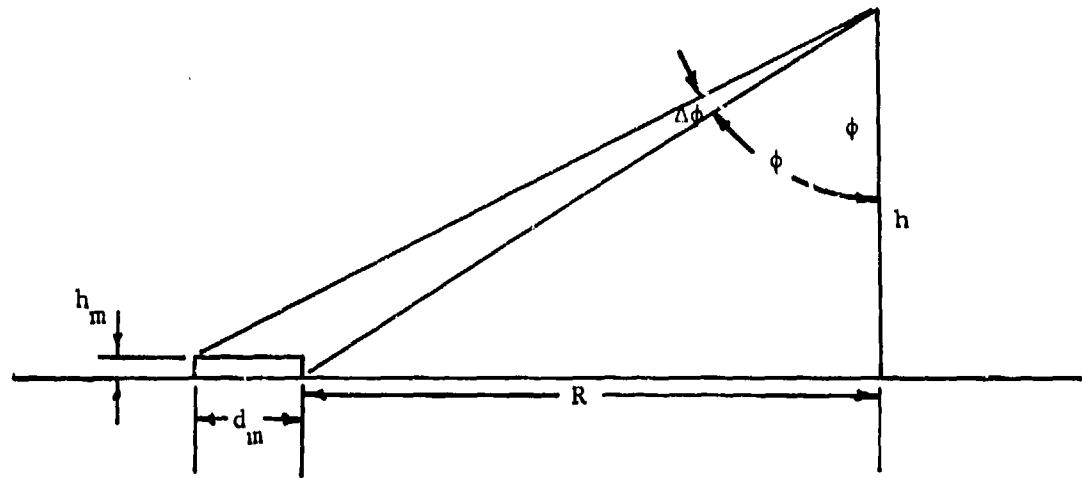
FIGURE 4.3-1. GEOMETRY USED FOR COMPUTING RESOLUTION LIMITED RANGE

TABLE 4.3-1
RESOLUTION LIMITED RANGE

AN/PAS-7	AN/PVS-4 Night Vision Sight Individually Served Weapons	AN/TVS-5 Night Vision Sight Crew Served Weapons	AN/PVS-5 Night Vision Goggles, Passive	Handheld Thermal View
Sensor Height h, in meters	1.7	1	1.7	1.7
Resolution Limited Range, R, in meters, Mine on Flat Surface	283	435	283	67
Resolution Limited Range, R, in meters on Surface with Ground Cover	67	65	67	32

0.126 m. The height, h, of the image intensifier is assumed to be 1.7 m, about eye height for a standing man or 1 m if the device is vehicular mounted. The calculated range values indicate that if mines were on a flat, plain surface, they would be observable at a few hundred meters providing there was sufficient contrast with the background.

These range values are highly optimistic since in the real world, the ground is not flat and in general, there will be cover such as grass obscuring the mines. If the cover is as tall as a mine (about 12 cm) so that h_m can be considered to be zero and only the mine tops are observable, the ranges are on the order of 67 m. If mines are tilted away from the observer by even a small amount, the mines will not be detectable. A standing man, 67 m away from a mine will not be able to see it if the mine is tilted by 1.45 degrees. The closer edge of the mine would only be 7.7 mm higher than the far edge. Thus, even if the contrast between a mine and its background is sufficient for detection purposes, the likelihood is that ground cover and ground irregularities will prevent detection of mines at ranges much over 50 m for image intensifier or thermal detection devices mounted on vehicles or used by ground personnel.

Suggestions have been made that night vision devices be flown on RPV's or other aircraft over minefields. The depression angle of the sensor can be increased up to 90 degrees, i.e., looking straight down, so that ground cover and terrain irregularities become less important. For these airborne cases as well as for the cases of night vision devices used on the ground, the sensor's field of view will limit the number of mines which can be seen at any given instance.

An example using the minefield as given in Scenario A and a sensor (AN/TVS-5) with a nine degree circular field of view pointing straight down, illustrates some of the problem areas. The diameter

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of the circle formed by interception of the field of view by the
ground is plotted as a function of altitude in Figure 4.3-2. If de-
tection range is limited by the contrast between mines and background
or by mine reflectance characteristics to 100 m or less, the observed
area at any instance is not large. At 100 m altitude, the diameter
is 15.7 m. In Scenario A, the minefield rows are 50 m apart and the
mines are 5.5 m apart on the average in each row. The maximum number
of mines which can be seen is only two at any instance and usually
no mines will be seen. In order to cover a suspected minefield area,
a patterned aircraft flight path plus sensor scanning would have to
be used. All observations would have to be integrated to determine
if a minefield pattern emerges. Integration requires a constant
knowledge of aircraft position and altitude as well as of sensor scan
pattern. In all likelihood, the sensor would have to be stabilized.

Longer detection ranges would ease the search problem somewhat.
Assume the flight altitude is 200 m. If the sensor is pointing down,
and the aircraft is over one minefield row, the maximum of mines
which can be seen is five as at Position A in Figure 4.3-3. As the
aircraft proceeds, the field of view encompasses portions of two rows
as at Position B and as many as 7 mines may be observed. Pattern
recognition algorithms may be difficult to apply because of the low
number of mines detected. One way to increase the area observed (C
in Figure 4.3-3) at any instant is to point the sensor somewhat for-
ward. The sensor depression angle cannot be too shallow because the
required detection range will be increased. At 45 degree depression
angle, the maximum range will be 308 m.

An examination of Figure 4.3-3 also makes clear that the aircraft
must make many passes over the minefield to determine its extent.
The number of passes made can be minimized if the direction of the
minefield rows can be surmised after the initial detection and the
aircraft flown over the suspected row positions.

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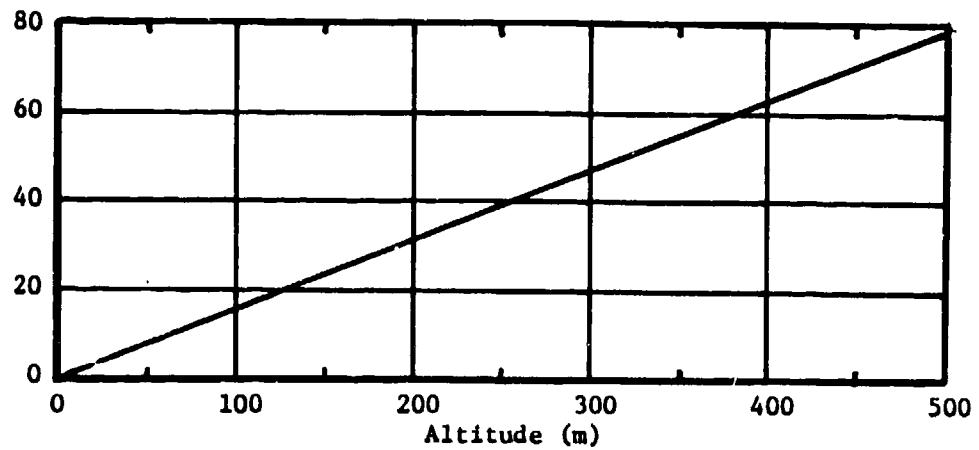
FIGURE 4.3-2. FIELD OF VIEW DIAMETER ON GROUND.
Nine Degree Field of View.
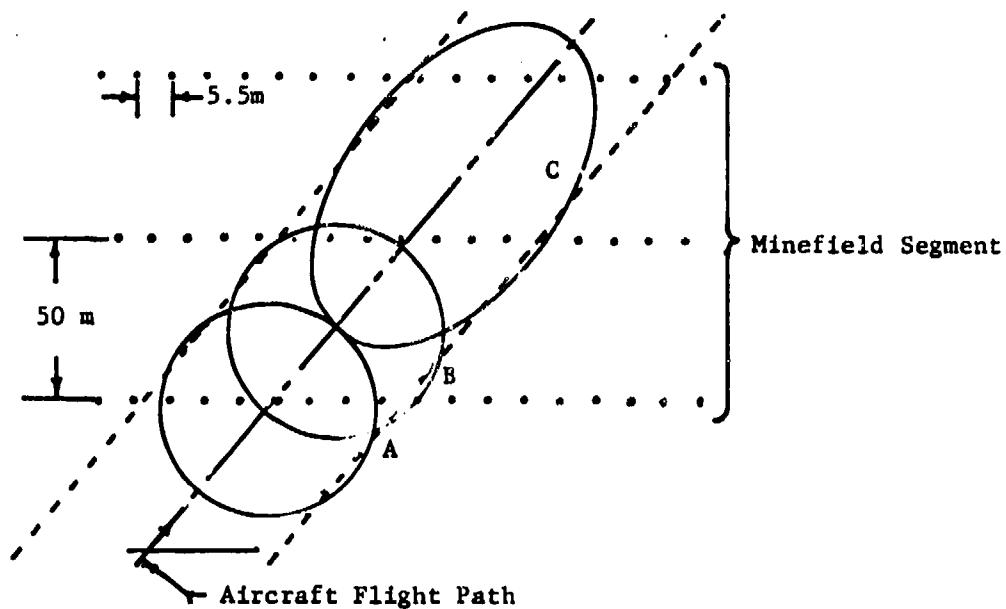
FIGURE 4.3-3. FIELD OF VIEW FOOTPRINTS AT 200m ALTITUDE

It is clear from the above discussion that detection range is an
important factor. It is clear also that using image intensifiers to
search for minefields from an aircraft is not a simple task since
even if the mines are detectable, provisions will have to be made
for keeping track of sensor pointing angles and aircraft positions.

The ability to infer the presence of a minefield is limited to
observing minefield laying operations. Vehicles can be detected and
recognized at ranges on the order of 400 to 600 m, depending on the
illumination available for the image intensifier devices. Men would
be observable at somewhat shorter ranges. Thermal viewers would
yield comparable ranges. With either type of device, one would have
to be sufficiently close to observe the motions of both vehicles and
men to infer minelaying operations. Walking patterns and stooping
motions are probably the best indicators. Unless an observer were
fortuitously placed, it would be unlikely that he could see minelay-
ing chutes on a vehicle. It is also unlikely that an entire minelay-
ing operation could be observed either because of lack of timeliness
or because of the extent of the minelaying operation.

Surface mines and minefields can probably be detected with night
vision devices but only at short ranges. If remote detection is de-
sired, some type of remotely controlled vehicle is required to carry
the sensor close to the suspected minefield area.

It is recommended that a few tests be designed to determine de-
tection ranges of surface laid mines using night vision devices.
These tests should be made under several lighting conditions and on
several kinds of ground cover. If detection ranges are short, on
the order of a few tens of meters, efforts in the use of night vision
devices should be confined to teaching soldiers to recognize minelay-
ing operations (detection of men and vehicles) when the opportunities
arise. If mine detection ranges are on the order of several hundred
meters, systems should be synthesized and examined from the technical
and operational viewpoints.

4.3.5 TELEVISION

Television is a potential candidate for detecting mines and mine-fields during daytime. A stabilized television camera mounted on a small RPV is currently in the engineering development phase for the U.S. Army artillery [10]. If it is assumed that the standard commercial television standards apply so that the frame size is in the ratio of 3 by 4 and there are 512 interlaced lines and if the vertical field of view is ten degrees, line spacing is 0.32 milliradians, the PRV will have to approach to within one kilometer of a minefield before individual mines can be resolved. The range may be considerably shorter if the contrast is poor between mines and background. As with the other electro-optical sensors, pattern recognition will have to be applied and the camera scanning pattern and the PRV path flown will have important effects on determining the location and extent of a minefield.

4.4 ACOUSTIC AND SEISMIC SENSORS

Acoustic sensors have been used by armies for a long time, particularly for locating artillery. Such systems, where several microphones are arrayed in a line on the friendly side of the FEBA, remain organic to artillery target acquisition batteries. These systems determine the direction of arrival of gunfire or of artillery bursts and a pair of systems can locate artillery pieces by triangulation.

It may be possible to detect secondary explosions of mines if some means of setting off the mines could be used. Minefield location would have to be suspected or known. Minefield location may be possible but not the location of individual mines. Location accuracies would be affected by atmospheric conditions, particularly winds.

Data on detection of mine explosions by sound ranging systems do not exist and would have to be measured.

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Prior knowledge of the general location of a minefield, poor lo-
cation accuracy for individual mines, and the possibility that detec-
tion will not be possible, make these acoustic ranging systems poor
candidates for the mine and minefield detection roles.

During the late Vietnam action, acoustic and seismic sensors were
used to monitor troop and vehicular movements along trails and roads.
Some of these sensors remain in the inventory. REMBASS (Remotely
Monitored Battlefield Sensor System) is a systematized use of these
types of acoustic and seismic sensors.

REMBASS will be used primarily for route surveillance in tactical
operations with sensors placed along roads. The seismic and acoustic
sensors are used to monitor mechanical energy changes produced by
enemy activities. Any information on activity of personnel or vehi-
cles which is detected is transmitted via radio to a classifier which
indicates time of detection and whether a vehicle is tracked or
wheeled. Radio range can be extended 15 km through the use of a
relay.

Sensor detection range is 500 m for both wheeled and tracked
vehicles and 50 m for personnel. Sensors are emplaced by hand, by
air drop or by artillery.

Classification is performed by examining the sound or seismic
spectrum obtained by using a Fast Fourier Transform algorithm. If
a signal cannot be classified, the presence of a target is noted.

The projected IOC is 1985. Department of the Army has asked that
the IOC be moved up for hand-emplaced sensors and the project office
will attempt to meet an IOC date in the latter half of 1981 for these
sensors. The balance of REMBASS is to be tested in the mid-to-latter
part of 1982.

Mines and minefields will not be detectable with REMBASS. The
REMBASS classifier is programmed to exclude artillery bursts so that

any such bursts and secondary explosions of mines would go
undetected.

Minelaying operations could be placed under observation with
seismic and/or acoustic sensors so that minelaying vehicles could be
detected. These sensors might be emplaced in sites likely to be
chosen by an enemy for offensive minefield operations. Alternative-
ly, the sensor would be emplaced by artillery. Since sensor detec-
tion ranges are not long, a substantial number of sensors would be
required to cover the likely minefield areas. Choice of sensor sites
would depend a great deal on tactical considerations and terrain
factors.

Two approaches appear possible for general use of acoustic and
seismic sensors for detecting mirefields or minelaying operations.
Neither approach is likely to be highly fruitful but deserve some
analyses and experimentation to ascertain difficulties and potential.

The first approach is to use artillery bursts to set off second-
ary explosions of mines. The key questions to be asked are:

1. How far can each shell burst set off secondary mine
   explosions?

2. Is a special shell required, for example, one filled with
   fuel air-explosives?

3. Does the artillery burst mask the signals from the secondary
   explosions?

4. Can positive classification be achieved?

If a shell, either existing or special, cannot be used to set off
several secondary explosions, this approach is not a useful one. It
appears possible to examine analytically the conditions necessary to
set off secondary explosions and also to determine if classification
can be achieved by examining audio and seismic spectra. Should de-
tection and classification by this means by possible, detection

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ranges should be determined to ascertain the number of sensors which
might be required to cover a given area.

The second approach to detecting minefield laying operations is
to infer such operations by detecting slowly moving vehicles. If
vehicles are to be detected, seismic/acoustic detectors could be 500
to 800 meters apart so that a few detectors could monitor a fairly
wide area. On the other hand, such detection could serve only as a
cue and no positive identification of minelaying operations would be
achieved.

The presence of men in the vicinity of a minelaying vehicle would
reinforce any inference about minelaying. However, vehicular signals
mask signals caused by personnel. Further, sensor detection range
for personnel is short, i.e., 50 m, so that many sensors would be
required. Similarly, the signals created by mines hitting the ground
when dispensed by chutes are likely to be masked. For these reasons,
it is recommended that this approach should not be pursued further.

4.5 EXPLOSIVE DETECTORS

Considerable interest exists both in military and civil sectors
in the ability to detect explosives. Mass spectrometry, biochemical
analysis, ion mobility, spectrometry, gas chromatography, animal
olfaction and a host of other techniques have been proposed and in
some cases have been examined extensively [11]. Experiments have
been performed and some devices such as x-ray machines have found
civil application. As a whole, these detection techniques do not
lend themselves readily to remote minefield detection because the
detectors' use involves bringing them in proximity to a mine.

Explosive detectors were first tried for detecting buried mines
in route clearing scenarios. Slow and insufficient search rates as
well as inadequate detection depths led MERADCOM to reject all but
vapor detection as explosive detection techniques. Another reason

for discarding these techniques was that they were not well suited for use on manuall; controlled ground vehicles. This problem could be expected to be aggravated for use in remote detection applications. In the case of surface mines, visual sensors would undoubtedly work at longer ranges and certainly faster. Some of the techniques involve the use of taggants in the explosives, a cooperative venture which cannot be expected of an enemy in wartime. Such detection techniques are excluded from consideration.

4.5.1 VAPOR DETECTION

Vapor detection of explosives consists of concentrating the vapor, analyzing the collected vapor to determine its constituents and deciding if explosives are present. As many as thirteen techniques are available for ionizing vapor molecules (Ref. 4.5.1, p. 103). Amont these are electron capture detectors, plasma chromatography, mass spectrometry and optical spectroscopy.

Concentrating explosive vapors on a battlefield is likely to be a difficult, if not impossible, task because of the high degree of clutter likely to exist and because of adverse weather conditions. Intermixing of vapors from individual mines and/or other explosives would make it impossible to pinpoint the location of buried mines unless a vapor concentrator were moved slowly over small areas. For these reasons, this approach is not recommended for the remote sensing of surface mines.

4.5.2 NUCLEAR METHODS OF MINE DETECTION

Nuclear methods of buried mine detection have been investigated extensively by the U.S. Mobility Equipment Research and Development Center, its predecessors and their contractors [12, 13]. It has been concluded that nuclear techniques are not feasible because of attenuation and because of background radiation from the soil overburden.

Imaging of back-scattered x-rays holds out some hope for detecting small near-surface anti-personnel mines.

Pursuit of nuclear techniques for detection of surface mines does not appear fruitful because other more readily available sensors such as image intensifiers and television can operate as well or better at longer ranges.

4.5.3 ANIMALS

Tests have shown that dogs and pigs have considerable success in detecting buried mines [14, 15]. Pigs have been excluded because of their living habits. Dogs can detect mines with high probability under many kinds of weather conditions [16]. An exception is in deep snow where mobility is impaired.

Eighty percent of all canine mine detections occur within two meters of a buried mine and ninety percent within three meters. For surface mines, dogs may not have to get as close, but in such cases, the mines should be as visible to the dog's handler. Generally, a handler accompanies each dog but there have been experiments conducted in which dogs responded to remote commands. When accompanied, dogs cannot be considered to be remote detection systems.

Although dogs are successful in detecting mines, their widespread use in remote detection of mines and minefields is not recommended. There are many reasons for this recommendation. Among them are that dogs and their handlers will be exposed to enemy action, that dogs will detect other explosives on a battlefield, that their search rate will be low, covering a 2 kilometer path, 3 to 4 m wide per working day, that dogs tire after about 2 hours work, and that handlers and dogs should be trained and kept together in teams. Further, dogs must be kept trained in peacetime if they are to be of any use in a short war. Such training is expensive, both in manpower and cost since one handler can train only two or three dogs at a time. Also,

new dogs must be trained continually because dog's lifetimes are
short.

4.6 SIGINT

SIGINT or signal intelligence is generally considered to be com-
posed of several parts. SIGINT has been defined in the "Dictionary
of Military and Associated Terms, (JCS Pub 1)" as "a category of in-
telligence information comprising all communications intelligence,
electronics intelligence and telemetry intelligence." ELINT is de-
fined as "technical and intelligence information derived from for-
eign, non-communications, electromagnetic radiations, emanating from
other than nuclear detonations or radioactive sources." COMINT is
defined as "technical and intelligence information derived from for-
eign communications by other than the intended recipients." Uninten-
tional electromagnetic radiation intelligence, sometimes called RINT,
falls under ELINT under the definition given above.

Electronic warfare support measures or ESM is a part of electron-
ic warfare (EW) and is defined as "that division of electronic war-
fare involving actions taken to search for, intercept, locate, and
immediately identify radiated electromagnetic energy for the purpose
of immediate threat recognition." The difference between SIGINT and
ESM primarily depends on the word "immediate" with ESM outputs used
for rapid targeting purposes. The term ESM matches minefield detec-
tion purposes better than does SIGINT.

There are no characteristics of mines or minefields which can be
used for detection or identification by SIGINT since mines and mine-
fields do not radiate RF signals.

The presence of the laying of a minefield or its location may be
determined from radio message contents but the probability is low
that messages ordering the laying of mines or the presence of a mine-
field would be broadcast. Even if such broadcasts are intercepted,

delays caused by decryption, translation, and communication links
are likely to decrease the usefulness of the message contents.

The great imponderable is whether or not messages concerning
mines and minefields are broadcast. It is recommended that if rec-
ords exist of messages intercepted while Warsaw Pact forces have , sen
conducting field exercises, such records be examined for any messages
concerning mines or minefields. If future exercises are monitored,
and there are positive intercepts, attempts should be made to corre-
late intercepted message centers with observed actions in minefield
laying, emplacement duration and minefield removal.

Any further action on SIGINT sensors should be deferred until
the above actions have been taken.

5
CONCLUSIONS AND RECOMMENDATIONS

The results of the initial sensor technical screening are summarized in Table 5-1. The table entries are based primarily on the results of studies previously performed by others and on qualitative estimates. The table results serve to aid in choosing those sensors which show the most promise in minefield detection and to eliminate from further consideration at the present time those sensors which show but little promise. Those sensors, namely MTI and pulse Doppler radars and acoustic and seismic sensors, which can provide inferential information and be used only for cueing purposes are eliminated at this time solely on the basis that these sensors do not directly detect mines.

A "yes" has been entered in the row entitled "Potential Applicability" if there appears to be some chance technologically that a sensor can detect mines and/or minefields some of the time. The entry "yes" does not imply that a sensor will work under all circumstances; in fact, many of the sensors will be limited by some factor such as weather or obscuration. Nor does the entry imply that all representatives of a sensor type can be used to detect mines and minefields. The potential applicabilities of these sensors are based on current knowledge or estimates of mine detection capabilities. As stated in the referenced sections, measurements will be required in many cases to ascertain with higher confidence whether or not a particular sensor type can be usefully applied to minefield detection.

5.1 CONCLUSIONS

The following conclusions have been drawn as a result of the initial screening.

1. Those generic sensor types which appear to be applicable to surface mine and minefield detection include photography,

TABLE 5-1
SENSOR CHARACTERISTICS

	Photo	SAR	Real Aperture mm-Wave Imaging Radar	MTI & PD Radars	Short Range Microwave	Non-Linear Harmonic	Acoustic/ Seismic	SIGINT
Ground/Air	Air	Air	Air	Gnd/Air	Active	Air	Gnd	Gnd/Air
Active/Passive	Passive	Active	Active	Active	Active	Active	Passive	Passive
Day/Night	D/N + Illum.	D/N	D/N	D/N	D/N	D/N	D/N	D/N
All Weather	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Direct Mine Detection	Yes	Yes	Yes	No	Yes	No	No	No
Minefield Pattern Recognition	Req.	Req.	Req.	N/A	No	N/A	N/A	N/A
Inferential Detection	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Surface	Yes	Yes	Yes	No	Yes	No	No	No
Buried	Yes	Yes	Yes	No	Yes	No	No	No
Detection Range (meters)	10^4	10^5	10^4	10^5	0.1	10^4	10^2	10^5
System Search Rate	Fast	Fast	Med.	Med.	Slow	Med.	Slow	N/A
System Reaction Times	Min. to Days	Secs to Min.	Secs to Min	Min.	Secs	Secs to Min.	Min.	Min. to Days
Sensor Example	KA-91A	AN/APD-10	Conceptual	SOTAS	VMR&DS	METRA	REMBASS	
Status	Op.	Op.	Conceptual	Op.	Dev.	Cancelled	Dev.	Op.
Potential Applicability	Yes (Sec. 4.1.2)	Yes (Sec. 4.2.1)	Yes (Sec. 4.2.3)	No (Cueing Only) (Sec. 4.2.2)	No (Sec. 4.2.4)	No (Sec. 4.2.5)	No (Cueing Only) (Sec. 4.4)	No (Sec. 4.6)

TABLE 5-1 (Continued)
SENSOR CHARACTERISTICS

	Passive IR	Multispectral	10.6 μm Scanner	Image Intensifier	TV	Explosive Detectors (Vapor, Nuc.)	Animals
Ground/Air	Air	Air	Air	Gnd/Air	Gnd/Air	Gnd	Gnd
Active/Passive	Passive	Passive	Active	Passive	Passive	Passive	Passive
Day/Night	D/N Trans.	D/N	D/N	Night	Day/N Illum.	D/N	D/N
All Weather	No	No	No	No	No	No	Nearly
Direct Mine Detection	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Minefield Pattern Recognition	Yes	Yes	Yes	Yes	Yes	No	No
Inferential Detection	Yes	Yes	Yes	Yes	Yes	N/A	N/A
Surface	Yes	Yes	Yes	Yes	Yes	N/A	N/A
Buried	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Detection Range (meters)	10^3	10^5	10^4	10^3	10^3	1	1
System Search Rate	Med.	Med.	Med.	Low	Med.	Very Low	Very Low
System Reaction Times	Secs to Min.	Secs to Min.	Secs to Min.	Secs to Min.	Secs to Min	Min.	Min.
Sensor Example	HRB-Singer Reconofax IV	Univ. of Michigan M-7		AN/TVS-5	Army RPV		Dogs
Status	Op.	Op.	Dev.	Op.	Dev.	Conceptual	Type Class. Exp.
Potential Applicability	Yes (Sec. 4.3.1)	Yes (Sec. 4.3.2)	Yes (Sec. 4.3.3)	Yes (Sec. 4.3.4)	Yes (Sec. 4.3.5)	No (Sec. 4.5)	No (Sec. 4.5.3)

active 10.6 micrometer scanners, synthetic aperture radars, real aperture mm wave imaging radars, multispectral scanners, passive scanners and television. Insufficient experimental data exists for all these sensors to rank order their potential effectiveness.

2. The electro-optical scanners all should detect surface mines with detection probability descending, under all conditions, in the order: active scanners, multispectral scanners, and passive single-channel scanners.

3. Criteria for the detection of a minefield are not necessarily the same as those for the definition of the location, orientation, and extent of the minefield. Suitable criteria for both detection and definition of minefields need to be developed.

4. All the sensors listed above require the aid of pattern recognition to determine not only the location of individual mines but to estimate the edges of minefield segments. Pattern recognition techniques may be the least difficult to develop for the synthetic aperture radar if considered solely on the basis of the size of the suspected minefield area monitored at any given instant. That is, a SAR can image a large part or all of a minefield in one "look" while other sensors will image only portions of a minefield.

5. A problem related to the pattern recognition problem is that of selecting the flight path to be flown or scanning pattern to be used so that once a portion of a minefield has been found, the flight path or scanning pattern can be adjusted to decrease the time required to find the remainder of the minefield.

6. Obscuration caused by natural features and man-made objects coupled with mine signature specularity can affect markedly

the prediction of detection probabilities. Small terrain features such as furrows and hummocks can conceal surface-laid anti-tank mines. Results of previous studies of gross terrain features, while useful for ascertaining where minefield detecting sensors can be used, are insufficient to tell how small terrain features will affect detection probabilities.

7. 'No one sensor stands out as the best mine detector from the technical standpoint. From the system viewpoing, coupling more than one sensor technique together appears to afford the greatest likelihood for surface minefield detection. For example, an MTI radar for cueing might be coupled with a synthetic aperture radar for mine and minefield detection.

8. Synthetic aperture radar is the only all weather sensor with the potential for long range detection of surface minefields.

5.2 RECOMMENDATIONS

1. Initiate preliminary system definitions incorporating singly or in combination, the promising generic sensors.

2. Define preliminary technical requirements for the preliminary systems. Develop methodologies and models for examining these systems with respect to the requirements.

3. Develop criteria for detection and definition of minefields.

4. Relate the probability of detection of a single mine to the probability of detection of a minefield.

5. Examine analytically both on technical and operational bases the potential for the postulated systems to detect and recognize ordered and randomized minefields.

6. Examine pattern recognition techniques and the related flight path and/or scanning problems.

7. Develop a methodology for determining the effects of small terrain features on obscuration.

8. Perform experiments with those generic sensor techniques which fulfill both the necessary technical and operational conditions, in order to provide experimental data to confirm analytical results and conclusions.

APPENDIX A
PLATFORM CHARACTERISTICS

A large number of platform types are available for mounting potential minefield detection sensors. Characteristics of a limited number of these platforms are given in this appendix. The platforms are chosen on the basis that they are already or will be in the Army inventory or because, in the case of the Aequare RPV, a similar unit is under development. The Canadair AN/USD-1 PRV is included because this unit has both a camera and an infrared scanner and is in use by the Canadian armed forces and the forces of the Federal Republic of Germany; this RPV might be adapted to fly minefield detection missions. Aircraft characteristics, fixed or rotary wing, are given in Table A-1.

Many ground vehicles are equipped with image intensifiers. Of these, the Improved TOW Vehicle (ITV) gives the best potential of any ground-vehicle system for looking over obscuring obstacles. The ITV has a hydraulically extendable dual TOW launcher and optical sight head. This allows sighting and firing to be performed from defilade with only the launcher exposed. The optical system consists of a 2.5x magnification, 25 degree field-of-view sight for acquisition and a 13x magnification tracker for daylight use. The AN/TAS-4 image intensifier is used at night. A FLIR may be used in the future. The overall height of the extended launcher at zero degree elevation angle is 3.25 m. The optical sight axis is about 3 m in height. The vehicle is a modified M-113A1 armored personnel carrier modified with the ITV kit.

Other ground vehicles which are or will be equipped with image intensifiers and FLIR's include the XM-1 and M-60 tanks. Neither these tanks nor any specialized ground vehicles which have been developed have the sensor elevation capability of the ITV.

TABLE A-1
AIRCRAFT CHARACTERISTICS

Nomenclature	Weights (lbs) Empty	Gross	Endurance or Range	Service Ceiling	Speed	Comments
OV-1 Mohawk	12,054	18,109	4.5 hrs	25,000 ft	180 knts 265 knts max.	OV-1D Photo, AN/APS-94 or IR scanner OV-1C Photo, IR Scanner
C-12A	7,722	12,500		29,200	260 knts at 14,000 ft	10 Place or Cargo
UH-60A Helicopter	10,900	16,450	287 nmi		160 knts 180 knts, max.	Utility, SOTAS
Aquila RPV	Launch Weight 150 lbs		120 nmi		100 knts	TV sensor, 12 Hz Reciprocating Engine, Radio Command
AN/USD-1	Launch Weight 238 lbs		12.5 min. 80 nmi		400 knts	Photo, IR Scanner Turbojet

Satellites are not viable candidates for bearing minefield detecting sensors. Cloud cover or poor weather have a maximum effect on photographic or electro-optic sensors. Sensors must be capable of achieving very high resolutions because of the small target sizes and the long ranges involved. Timeliness of coverage is another factor which vitiates sensor use on platforms. In low orbits, satellite periods can be short, but because of the short range from the satellite to its horizon, minefields will be in view only for short periods or not at all. At higher satellite altitudes, larger areas are in view for longer periods of time, but more than one satellite is required to keep a given area in view at all times. A given area can be monitored continuously from geostationary orbits (35,440 km) but the resolution requirements on the sensors are prohibitive.

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